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Evaluation of Contribution of Wind Blown Dust from the Desert to Levels of Particulate Matter in Desert Communities

GCA Corp.
Bedford, MA

Prepared for

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Evaluation of Contribution of Wind Blown Dust From the Desert to Levels of Particulate Matter in Desert Communities

by

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It is recommended that additional field programs be carried out to define the level and sources of the inhalable fraction of suspended particulates.

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SECTION 1

INTRODUCTION AND SUMMARY

Several large cities located in the southwestern United States have not yet attained the primary and/or secondary national ambient air quality standards (NAAQS) for total suspended particulates. These cities are located in desert environments; their major economic activities tend to be tourism, agriculture, or provision of services, rather than heavy manufacturing. As would be expected, studies of several of these cities have shown that these areas experience relatively little pollution from industrial point sources; however, widespread fugitive dust problems do exist.

At present, there are differing opinions concerning the contributions of fugitive dust from human activities and of wind-blown dust from the surrounding desert to this nonattainment problem. To help resolve this issue, GCA was asked to review existing data and studies and assess the impact of wind-blown desert dust on particulate levels within such cities.

Figure 1 indicates the approximate study area considered. It includes the semi-arid regions of the southwestern states and extends from the Sacramento and San Joaquin valleys in California to central Texas and Oklahoma. Although information was reviewed for nonattainment sites throughout the region, studies of Phoenix and Tucson, Arizona, and Las Vegas and Reno, Nevada contained the most useful information for the purposes of the required assessment. For this reason, this report focuses on these four cities.

The report is organized into five sections. This section provides an introduction, summarizes the major findings, and presents conclusions and recommendations. Section 2 describes the principal analytical techniques used in the studies reviewed. Section 3 summarizes annual and 24-hour concentration data from remote and rural sites throughout the southwest. It also discusses chemical and physical properties of background particulates. Section 4 examines the distribution of particulates in and around the four study cities and compares the distributions with patterns of land usage and human activities. Section 5 discusses characteristics and sources of urban particulates, focusing on the contribution of wind-blown desert dust. It includes a summary of particle size measurements that emphasize the inhalable size fraction.

MAJOR FINDINGS

The authors of this report have reviewed numerous published documents and some recent air quality data in an attempt to define the contribution of wind-blown desert dust, and its inhalable fraction, to the TSP nonattainment problem in large cities set in desert surroundings. From this review, a

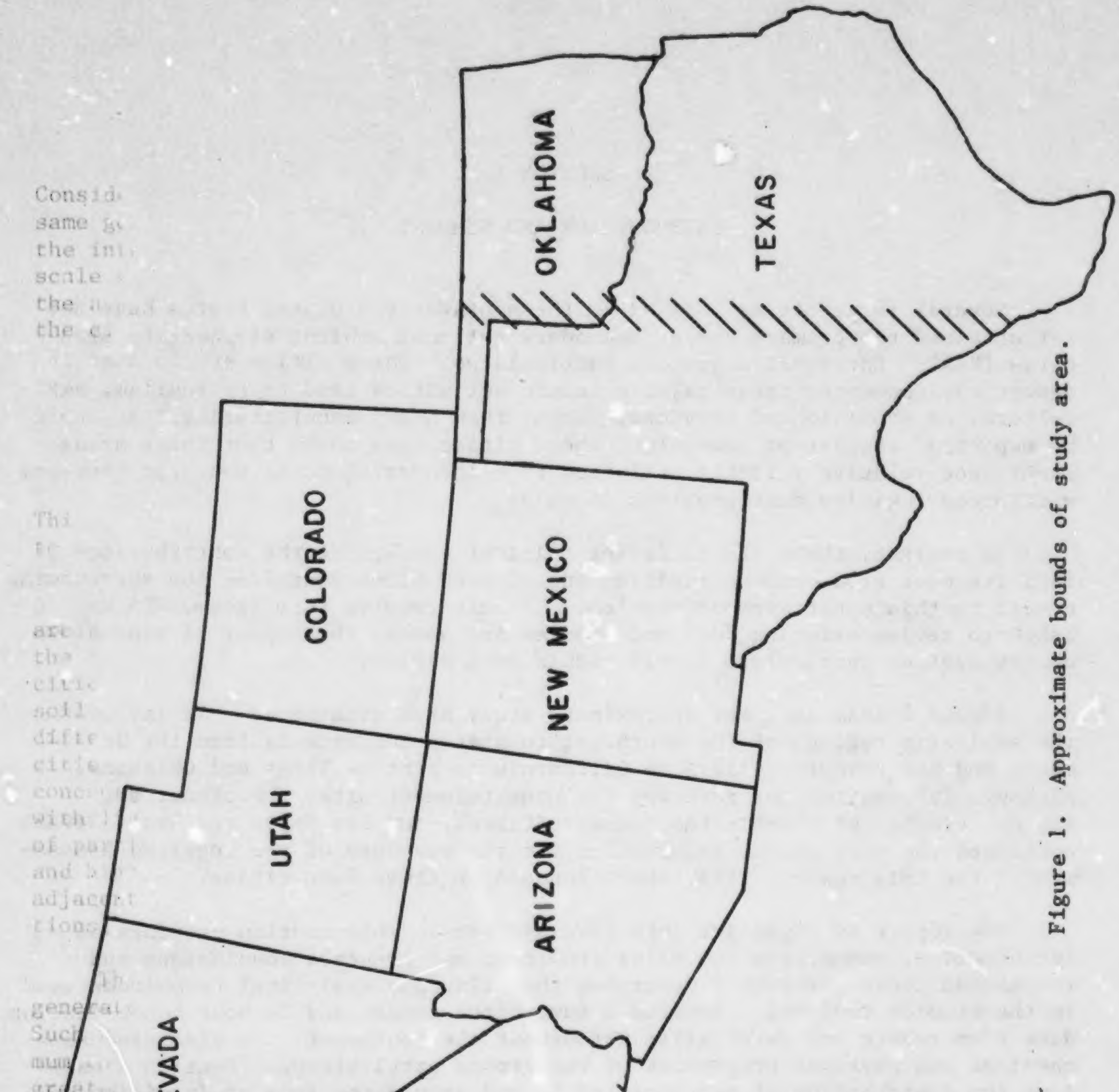
OKLAHOMA
TEXAS
COLORADO
NEW MEXICO
UTAH
ARIZONA
NEVADA
CALIFORNIA

Figure 1. Approximate bounds of study area.

concensus emerges that the part played by dust blown in from the undisturbed desert is very small, and can safely be ignored when developing control strategies. With the principal exception of contributions during widespread dust storms - one of the occasional natural phenomena the effects of which may be disregarded in control strategy development - its impact is contained within the low background levels of approximately 25-30 $\mu g/m^3$ found throughout the Southwest. When major duststorms do occur, they are fed principally by emissions from disturbed surfaces. These emissions increase rapidly near urban areas as a result of increasing construction, agriculture, and similar activities. Severe duststorms occur perhaps once or twice a year in the study area during periods of sustained high winds; their frequency can be much higher in the agricultural regions of the Great Plains, particularly during drought conditions.

In this summary discussion, the major findings of the reviewed reports have been organized around the four principal analytical techniques described in Section 2. Although the findings are sometimes taken directly from the reports, they more often represent a condensation and integration of ideas by the GCA reviewers. The description of TSP and land use relationships is based on an analysis carried out by GCA for this report. Emphasis is placed on the interpretation of the air quality data; information provided by the remaining techniques is considered supportive, but not conclusive. Throughout the summary, reference is made to more complete discussions of the various findings provided within the body of the report.

The particle size data that were available were too limited and inconclusive to be of much help in defining the inhalable particulate levels either in the desert or within the urban areas.

TSP and Land Use Relationships

The analysis of TSP concentrations in and around Phoenix, Tucson, Las Vegas and Reno presented in Section 4 shows a close relationship between the spatial distribution of concentration and land use and its associated human activities. Generalizing, annual geometric mean concentrations increase steadily as one progresses from remote and rural regions to the urban core. The increase in concentration roughly parallels an increase in the emission density of fugutive dust. In leaving the remote area one first encounters areas with increasing amounts of dust generated by traffic on unpaved roads and by agricultural activities. Pockets of urbanization, both residential and commercial, are reached next with an accompanying increase in vehicular traffic; construction activities become significant sources. In drawing closer to the urban core, the density of residential and commercial property continues to increase, and with it vehicular associated emissions, including direct tail pipe emissions and entrained street dust.

The overall effect of changing land use patterns and increasing emission density on concentration is shown by the following average values derived from the concentration fields around the four cities:

Site Characteristics	Average Concentration
Remote or rural	30 μg/m^3
Suburban/residential, commercial	81 μg/m^3
Center city/commercial	124 μg/m^3

Considerable variation in concentration does occur within areas having the same general land use classification, however, as a result of differences in the intensity of the associated human activities plus differences in small-scale site characteristics. For example, a direct relationship exists between the average center city concentration found within each of the four cities and the city's population, as shown below:

	Reno	Las Vegas*	Tucson	Phoenix
Population	82,500	201,300	301,200	684,500
Mean concentration, μg/m^3	77	100	133	184

This relationship is further evidence that the particulate emissions leading to nonattainment within the cities are generated by urban activity.

The overall behavior of 24-hour concentrations in and around the urban areas agrees closely with that of the annual averages; that is, violations of the secondary standard rarely occur in the outlying areas surrounding the cities, but do occur with increasing frequency as the proportion of disturbed soil surfaces and the amount of vehicular traffic increases. Although details differ from city to city due to differences in the physical setting of the cities and in the distribution of urban activities, the occurrence of high concentrations typically fall into two patterns. One pattern is associated with light winds and low mixing heights which severely limit the dispersion of particulates. Under these conditions, wind-generated emissions are absent and high concentrations develop within the central city and the immediately adjacent area where human activity peaks. Under prolonged stagnating conditions, high concentrations become more widespread.

The second pattern is associated with strong winds during which wind-generated fugitive dust plays a significant and sometimes dominant role. Such periods are of relatively short duration (hours rather than days). Maximum concentrations on strong wind days are generally found in areas with the greatest amount of exposed, disturbed surface. In the case of Phoenix, the largest urban area studied, the observed maximal 24-hour concentrations (1973-1975) at sites classified as rural/residential and surrounded by fugitive sources were approximately twice the maximal values observed within the central city.

One additional feature of the air quality data is of major significance. Site by site comparisons of annual and 24-hour concentrations observed either within or near the urban core of the larger cities disclose large differences.

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*Including North Las Vegas.

Some of the differences among proximate sites are attributable to differences in monitor height; others are judged to be a reflection of the distribution of local fugitive dust sources. For example, the 1977 annual geometric means at four Tucson sites located within a few miles of one another were 122, 158, 68 and 119 μg/m^3; the heights of the monitors were 25, 15, 80 and 18 feet, respectively. The large concentration gradient shown in the vertical is indicative of ground-level sources of large particulates with relatively short horizontal travel distances. The difference of 39 μg/m^3 between two sites whose heights differ by only 3 feet is most easily attributed to differences among local sources. These differences are also reflected in the 24-hour measurements at the two sites. Out of 57 sampling days in 1977, the number of exceedances of the secondary standards at the site with a mean concentration of 119 μg/m^3 was 12, while 35 exceedances were observed at the site with a mean of 158 μg/m^3.

Details of these analyses are given in Section 4.

Emission Inventories and Modeling

Emission inventories for particulates have been carried out throughout the Southwest. These inventories vary in detail from county- or AQCR-wide estimates to microinventories around specific nonattainment sites. The inventories have been used in dispersion models of different degrees of complexity in some of the urban areas to calculate the impact of specific categories of emissions on TSP levels. All of these studies are consistent in stressing the dominant role played by fugitive dust emissions from unpaved roads, reentrained street dust, construction activity and wind erosion from agricultural fields and other disturbed surfaces. Although total emissions from the undisturbed desert are estimated to be substantial, they are distributed over large areas outside of the urban centers and therefore have little impact on the urban monitors. Conclusions from several of these studies follow.

An emission inventory and modeling study covering the Phoenix area was carried out by TRW. TRW concluded that nearly all of the TSP above background was caused by emissions from unpaved roads, entrained street dust, construction activities, and wind erosion from agricultural fields, unpaved roads, undisturbed desert, tailings piles, vacant lots and the like at 12 of the 13 sites studied. Off-road vehicles were considered to be primarily responsible for violations at the 13th site. The sites most affected by wind erosion were in rural areas under development. The impacts of the various classes of wind-erosion sources were not disaggregated in the model results as presented. Emissions from disturbed soil surfaces were highly concentrated in the urban portion of the region. In a separate study which developed an emissions inventory for Maricopa County, PEDCo found that wind erosion from agricultural land was the biggest single contributor to county-wide emissions, followed by unpaved roads. From another modeling study for the Phoenix area, carried out by the University of Texas, it was concluded that the high concentrations of particulates experienced during late fall and winter periods of atmospheric stability are associated with local fugitive dust sources. Advective transport of dust from the countryside to the urban areas was judged to be unimportant. Details of these three studies can be found in Section 5, pages 65, 75, and 64, respectively.

In a study of the Las Vegas and Reno areas, PEDCo developed gridded emission inventories. These inventories showed that emissions in both cities are concentrated in the more urbanized portions of the study areas. PEDCo concluded that approximately 80 percent of the total emissions in both cities comes from fugitive dust sources. Unpaved roads were estimated to be the largest contributor, followed by natural surfaces and paved roads. This study is discussed more fully in Section 5, p. 80.

PEDCo also studied 35 nonattainment sites in Colorado and Utah, none of which were in rural locations (see Section 5, p. 85). PEDCo concluded that the principal sources of particulates in large and moderate sized urban centers are traffic related. These include reentrained street dust, winter road sanding, and motor vehicle exhaust. In medium and small urban centers, however, the major sources were found to be point sources, unpaved roads, construction, and wind-blown dust from agricultural fields and other open areas.

One other related study was reviewed. In this study, Engineering-Science investigators developed microinventories around five nonattainment sites in Albuquerque and modeled each site (see Section 5, p. 85). They concluded that from 42 to 61 percent of the particulates at these sites were from unpaved roads or driveways, paved roads, fire and exhaust emissions, and unpaved parking lots.

Chemical, Elemental, and Morphological Analysis

Chemical and elemental analyses coupled with correlation and enrichment factor techniques showed that approximately 50 percent of the suspended particulate matter in the Tucson area was composed of soil. The values at 11 sites ranged from 48 to 83 percent, with the lowest estimate being obtained at the background site. It was not clear that the percentage of soil material was significantly greater in the urban area than at the background site, but even if it were not, the much greater absolute TSP concentrations within the city imply major contributions from urban soil sources. Unfortunately, the analytical techniques cannot distinguish between wind-blown desert soil and soil suspended as the result of human activities such as travel on unpaved roads. A description of this analysis begins on p. 72 of Section 5.

Microscopic analyses performed on particulate samples collected in Phoenix led the participants in another field study (see Section 5, pp. 63-64) to conclude that the particles were not typical of wind-eroded materials. It was concluded from this study that vehicular traffic, especially on unpaved roads, was the primary generator of TSP within the Phoenix area, and that long-range transport of aerosols by winds from the surrounding deserts was only a minor source.

Meteorology

The meteorological parameters that most often correlate significantly with TSP levels are precipitation and wind speed, although the effect of wind speed is confounded by two opposing phenomena. When emissions remain constant, concentrations decrease with increasing wind speed due to increased dilution; on the other hand, once wind speed reaches a critical level, further increases lead to an increasing amount of wind-generated dust. In one of the reports reviewed (see Section 5, pp. 86-92) meteorological relationships were used as the basis for estimating the contribution of wind-blown dust (not disaggregated by source type) to TSP nonattainment in EPA Region VI. The importance of wind-blown dust was judged by the degree to which high TSP concentrations were associated with high winds and low precipitation. Using the AID decision-tree program as the analytical tool, it was decided that wind-blown dust was the primary contributor to high TSP levels at one of the seven sites (Lubbock, Texas). This technique leads to only very qualitative evaluations.

CONCLUSIONS AND RECOMMENDATIONS

The review of past studies carried out in the Southwest has led us to the following conclusions. First, the contribution of wind-blown dust from the undisturbed desert floor to particulate levels in desert communities is very small and should be considered as part of the low-concentration background when developing control strategies. Second, if human activities, such as the use of off-road vehicles, repeatedly break up the desert crust, local violations of the 24-hour standards are likely. Third, the contributions of the various source categories of fugitive dust to the nonattainment problem cannot be accurately disaggregated with the techniques employed in the reviewed reports. However, these techniques can be used to identify the major contributing source types, and there is now substantial agreement not only on the major source types but also on the characteristics of the urban localities most affected by each type.

Thus, there already appears to be sufficient information to serve as a sound basis for the development of strategies leading to an overall improvement in air quality. The spatial application of control measures can be fine tuned to some extent on the basis of current observations and microinventories around problem sites. Special monitoring programs can be used to define the impact of individual sources if desired.

The one area where additional field programs are needed is in defining the level and sources of the inhalable fraction of suspended particulates. The collection of samples over short averaging times (e.g., 1 or 2 hours) along a line through an urban area and oriented with the prevailing wind would be invaluable in assessing the relative impacts of locally generated and transported inhalable particulates. The use of instrumentation providing respirable, inhalable, and total particulate data is recommended. This detail would be helpful in evaluating conformance to possible future standards as well as in assessing source impact.

SECTION 2

ANALYTICAL TECHNIQUES

INTRODUCTION

This section introduces the analytical techniques used in particulate studies reviewed for this report. Four types of analysis are discussed: (1) analysis of temporal or spatial patterns of suspended particulates; (2) analysis of particulate emissions; (3) examination of chemical, elemental, or morphological properties of suspended particulates; and (4) examination of the impact of meteorological conditions on suspended particulates. The discussion focuses on techniques' strengths and weaknesses in assessing the contribution of wind-blown desert dust to urban particulate concentrations. The section concludes with an overview of where these techniques were applied within the study area.

ANALYSIS OF TEMPORAL OR SPATIAL PATTERNS OF SUSPENDED PARTICULATES

This category includes many of the most commonly used techniques in particulate analysis. Analysis of temporal patterns encompasses techniques such as trending and examination of seasonal and daily fluctuations in particulate concentration. Spatial analysis includes comparison of particulate concentrations by site environment, inter-site correlations, and mass flux determinations.

In the type of problem this report deals with, spatial analysis is particularly important, but temporal analysis also has a role to play. Several studies reviewed for this report examined seasonal patterns of particulate concentrations, often in conjunction with analyses of seasonal meteorological fluctuations. One of these studies concluded that seasonal patterns implicated fugitive dust, rather than wind-blown desert dust, as a major contributor to the particulate problem in the Phoenix area.[1]

Spatial patterns play a prominent role in the analysis presented later in this report. One technique frequently relied on is comparison of particulate concentrations by site environment. Comparison of urban and background particulate concentrations, for example, reveals a great deal about the contribution of wind-blown desert dust to high particulate concentrations in urban areas. Other spatial analysis techniques also provide information that is helpful in assessing the contribution of wind-blown desert dust to urban particulate concentrations. Inter-site correlations, which were relied on in several studies, can indicate whether geographically disperse sites are influenced by the same source or type of source. In Tucson, for example, concentrations of Al, a soil indicator, at the background location correlated very poorly with Al concentrations at urban locations.[2] This evidence suggests that different sources (or processes) may be responsible for introducing soil into the atmosphere in urban and background locations. Upwind/downwind and mass flux analyses were also used to assess the transport of wind-blown dust from the desert into urban areas.

ANALYSIS OF PARTICULATE EMISSIONS

The studies reviewed for this report relied heavily on emissions inventories, microinventories, and air quality modeling. The two inventory techniques are similar in many ways; both attempt to identify sources in some bounded geographic area, then estimate emissions from these sources. The major difference between the two techniques is the scale of the analysis: microinventories focus on small geographic areas - often a 1- to 5-mile radius around a monitor; emission inventories usually encompass a larger geographic area. Air quality models, which range from very simple to very sophisticated, translate the emissions documented in inventories into ambient concentrations.

One drawback of emission inventories/microinventories is that they often ignore natural emissions such as wind-blown desert dust or treat these emissions in a very cursory manner. Although many of the inventories reviewed for this report suffered from this flaw, they do give a sense of the magnitude of other sources - such as paved and unpaved roads - contributing soil material to the atmosphere in urban areas. Air quality modeling is potentially very useful in assessing the impact of wind-blown desert dust on urban air quality since one of its purposes is to estimate source contributions to ambient concentrations. Its usefulness is limited by the accuracy and completeness of inventory input, however. Several studies examined in this report relied on air quality modeling.[3-7]

CHEMICAL, ELEMENTAL, AND MORPHOLOGICAL ANALYSIS

Technological advances have enabled scientists to characterize the chemical, elemental, and morphological properties of suspended particulate matter. This section deals with a variety of techniques used to analyze this detailed data including enrichment factors, inter-species correlation and factor analysis.

Many of these techniques are quite useful in identifying sources of particulate matter. Inter-species correlations, for example, indicate whether certain components of particulate matter cluster together; a common source is usually hypothesized for such clusters. In the Tucson study by Moyers et al.,[2] the elements Al, Fe, Si, Ti, Li, Rb, Mg, Na, Ca, K, Mn, and Sr were correlated with each other. The authors suggested soil or crustal material as a possible common source for this cluster of elements. Factor analysis is a refinement of inter-species correlation that serves much the same purpose. Statistical analysis based on inter-species correlations is used to group elements into several clusters. The analyst then draws on his experience and knowledge to hypothesize about the factor - in this case, the source - that generates each cluster of elements.

Enrichment factors try to distinguish anthropogenic and "natural" sources by examining the concentration of elements in suspended particulate matter relative to their concentration in soil material. An enrichment factor of one indicates that the element has the same relative concentration in both air and soil, implying a "natural" soil-related source. An enrichment factor greater than one indicates that a particular element is more abundant in air than in soil, suggesting contributions from anthropogenic sources. In the Tucson study, enrichment factors for the 12 elements suspected of being soil-related (see list above) were similar, all very close to one. This reinforces the evidence provided by inter-species correlations that these elements, which comprise a large part of the particulate matter in the Tucson study, have a common source, soil.

Most of these techniques are incapable of distinguishing between fugitive (man-made) dust and natural wind-blown desert dust, although they can indicate how much these two sources, taken together, contribute to particulate concentrations. Several of the techniques discussed earlier, for example analysis of spatial patterns, can help distinguish between these two sources when applied to chemical and elemental data. Spatial analysis of soil-related elements in the Tucson study showed that concentrations of soil-related elements were much different at urban sampling sites compared to the background site. The authors concluded from this evidence that much of the suspended soil material in Tucson is probably due to urban activity. Inter-site correlations in Tucson also indicate that soil concentrations in urban and background locations were dissimilar.

Morphological analysis can also distinguish between natural and anthropogenic sources of suspended dust particles. A recent study of particulates in Phoenix,[8] for example, used morphological data to distinguish the sources of mineral material found in particulate samples. They found that the particle sizes and shapes of most of the mineral particles in the Phoenix samples were not typical of wind-eroded materials; instead, the particles were often sharp and angular indicating, according to the authors, vehicle travel over paved roadways.

METEOROLOGY AND SUSPENDED PARTICULATES

This technique focuses on relationships between meteorological parameters, such as wind speed, precipitation, and mixing height, and levels of suspended particulates. Most studies reviewed for this report relied on common statistical techniques such as linear regression or correlation coefficients to examine the relationship between meteorology and particulate concentration.

Many of these studies found the complexity of the TSP/meteorology relationship defied analysis by simple statistical techniques. Several studies, for example, focused on the relationship between wind speed and particulate concentrations, hoping to distinguish the relative importance of wind-blown dust. Most found it difficult to sort out the conflicting influences of increased wind speed: (1) increased emissions which tend to produce higher TSP concentrations and (2) greater dilution of pollutants, which results in lower concentrations. Even studies that focused exclusively on the TSP/meteorology relationship[9] emphasized the qualitative nature of their results and the inability of the techniques available to distinguish between wind-blown desert dust and wind-blown dust from construction sites, unpaved roads, and agriculture sites.

OVERVIEW

Table 1 indicates which techniques were used in the studies relied on most heavily in the preparation of this report. The table reveals several noteworthy patterns. Perhaps the most noticeable pattern is the wide variety of techniques employed by the three studies of Phoenix; techniques from all four categories are used in these studies. The study of Tucson also used a large number of different approaches to analyze particulate problems.

The second distinctive pattern is the heavy reliance of the studies on emissions inventory and modeling approaches. Eight of the eleven studies utilized these approaches, six exclusively. While some of this information was very useful in assessing the contribution of wind-blown desert dust to urban particulate concentrations, many of the inventories suffered from the flaws discussed above limiting their usefulness.

These two patterns help explain why this report concentrates heavily on Phoenix and Tucson: a great deal of detailed and useful information about the nature of the particulate problems in these two cities had already been compiled. Less information was available in the published reports on other cities. This study also examines Reno and Las Vegas because the emission inventory done by PEDCo includes an assessment of the contribution of wind-blown desert dust.

TABLE 1. PRIMARY TECHNIQUES USED BY STUDIES RELIED ON IN THIS REPORT

	Regional Studies • Investigation of Fugitive Dust, Vol. 1, 2, PEDCo, 1974.	• Characterization of Particulate Sources Influencing Monitoring Sites in Region VIII Nonattainment Areas, PEDCo, 1976.	• Statistical Analysis of TSP and Meteorological Data in EPA Region VI, Technology Service Corporation, 1978.	Arizona • Aerosol Sampling and Analysis, IITRI, 1978 (Phoenix).	• Dust Transport in Maricopa County, Arizona, University of Texas, 1978 (Phoenix).	• An Implementation Plan for Suspended Particulates in the Phoenix Area, Vols. 1-4, TRW, 1977.	• Identification and Analysis of Urban Air Quality Patterns, University of Arizona, 1977 (Tucson).	• A Comprehensive Emission Inventory for Mohave and Yuma Counties, PEDCo, 1978.	New Mexico • Fugitive Du.t Emission Study for the City of Albuquerque, Engineering Science, 1979.	Nevada • Nevada Particulate Control Study for Air Quality Maintenance Areas, Reno and Las Vegas Urban Areas, PEDCo, 1977.	California • Technical Assistance in Developing Nonattainment Plans for Selected Areas in California, PEDCo, 1979.
Analysis of Spatial or Temporal Patterns											
Seasonal Patterns						X	X				
Comparisons by Site Environment		X				X	X				
Inter-Site Correlations							X				
Mass Flux Determinations				X							
Emissions and Modeling											
Emission Inventory	X					X		X	X	X	
Microinventory		X							X		X
Air Quality Modeling	X	X			X	X			X	X	X
Chemical, Elemental and Morphological Analysis											
Interspecies Correlations							X				
Enrichment Factors							X				
Factor Analysis							X				
Pattern Recognition							X				
Particle Size Analysis				X			X				
Morphological Analysis				X						X	X
Other Elemental Analysis											X
Meteorology and Suspended Particulates											
Regression Analysis			X								
Other			X			X	X				

SECTION 3

BACKGROUND SUSPENDED PARTICULATES

The expression background suspended particulates, as generally used, refers to particulates found in the atmosphere in remote or rural places well removed from obvious anthropogenic sources. Some of these particulates come from nearby natural sources; others are transported from distant natural and urban sources; still others are formed within the atmosphere by chemical action during precursor transport. In this report, background concentration is considered to be the concentration of particulates that would have existed throughout the study area had that area remained undisturbed by man. Conceived of in this way, background concentrations represent baseline levels upon which particulates generated within an urban area are superimposed. The difference between background and observed concentrations represents the increment that may be manipulated through the use of local control measures. The concept is somewhat simplisitc since the background really comprises a dynamic particulate population continually responding to changing depletion and replacement rates.

Background concentrations are usually expressed in terms of annual geometric mean concentrations measured in remote or rural areas unaffected by local sources. In addressing the influence of wind-blown desert dust on the nonattainment problem in urban areas, however, consideration must also be given to the magnitude of 24-hour concentrations observed in remote and rural areas.

This section first summarizes annual and 24-hour concentrations observed at remote and rural sites throughout the Southwest. It then discusses some of the physical and chemical properties of particulates in outlying areas in an attempt to shed light on their origins and probable transport distances. Topics discussed include: (1) particulate size distributions, (2) the generation of wind-blown dust, and (3) chemical constituents of suspended particulates. This information, when compared with that presented for urban areas in Sections 4 and 5 of this report, will be used in estimating the contribution of wind-blown dust to the TSP nonattainment problem in large cities set in desert surroudings.

BACKGROUND CONCENTRATIONS

Background concentration data have been assembled from three sources and are based principally on measurements made in 1976. Large year-to-year variations in background concentrations are not expected, however, barring extreme differences in meteorological conditions. Data obtained from the National

Aerometric Data Bank for 24 remote and rural sites throughout the eight southwestern states provides the most widespread set of annual and 24-hour concentrations. This data set is supplemented by measurements made at 20 sites in the Four Corners area for EPA by the Ute Research Laboratories.[10] In addition, contractor reports provide estimates of background levels for several specific urban areas.

Appendix A lists the location of each monitor, the station type as classified by the SAROAD site identification procedure, elevation above sea level, and the elevation of the monitor above the ground. Annual geometric mean concentrations, and the highest and second highest concentrations for the year, or period of measurement, are also given. The approximate locations of the monitors are indicated on maps (Figures A-1 and A-2).

Descriptions of the stations operated by the Ute Research Laboratories can be found in Reference 10. Typically, these stations were located on either Indian Reservation or National Park land in arid areas with sparse vegetation and widely scattered homes. Nearby land use was generally restricted to livestock grazing; in a few cases, limited areas were devoted to agriculture. The high-volume air samplers were mounted on 4.6 m (15 ft) towers to minimize the effects of local dust and ground-level obstacles.

Annual Geometric Mean Concentrations

Figure 2 displays the annual geometric mean concentrations obtained from the National Aerometric Data Bank. At three stations, the 1976 data did not meet the SAROAD summarization criteria for the calculation of annual means, and 1977 means were substituted; these three 1977 values have been placed in parentheses. The results from special monitoring programs conducted in northeastern Utah and northwestern Colorado are given as ranges. In each case, the results from four monitors were combined.

Although the results show no sharply defined pattern, the lowest values tend to be found in northern Utah and Colorado. At lower latitudes, concentrations of 50 $\mu g/m^3$ were measured in central Oklahoma and central Texas, perhaps reflecting regional differences in land use and agricultural practices. The only concentration that exceeded federal ambient standards, 84 $\mu g/m$, was measured at the Kern Wildlife Refuge in the San Joaquin Valley airshed in California. Examination of long-term trends at this site[11] suggests an improvement in air quality since 1976; in 1978, the annual geometric mean was 62 $\mu g/m^3$. Neither of these values, however, is representative of background concentrations.

Figure 3 displays geometric means observed by the Ute Research Laboratories monitoring network. Activation dates for the monitors ranged from 12 January 1976 to 6 May 1977 (see Appendix A, Table A-1). The values plotted in Figure 3, however, were calculated using 1976 data from sites where observations were available for at least three seasonal quarters. As the figure shows, the monitors stretched along an east-west belt 50-100 km wide that extended for a distance of about 380 km. Geometric means within the network ranged from 12 to 56 $\mu g/m^3$.

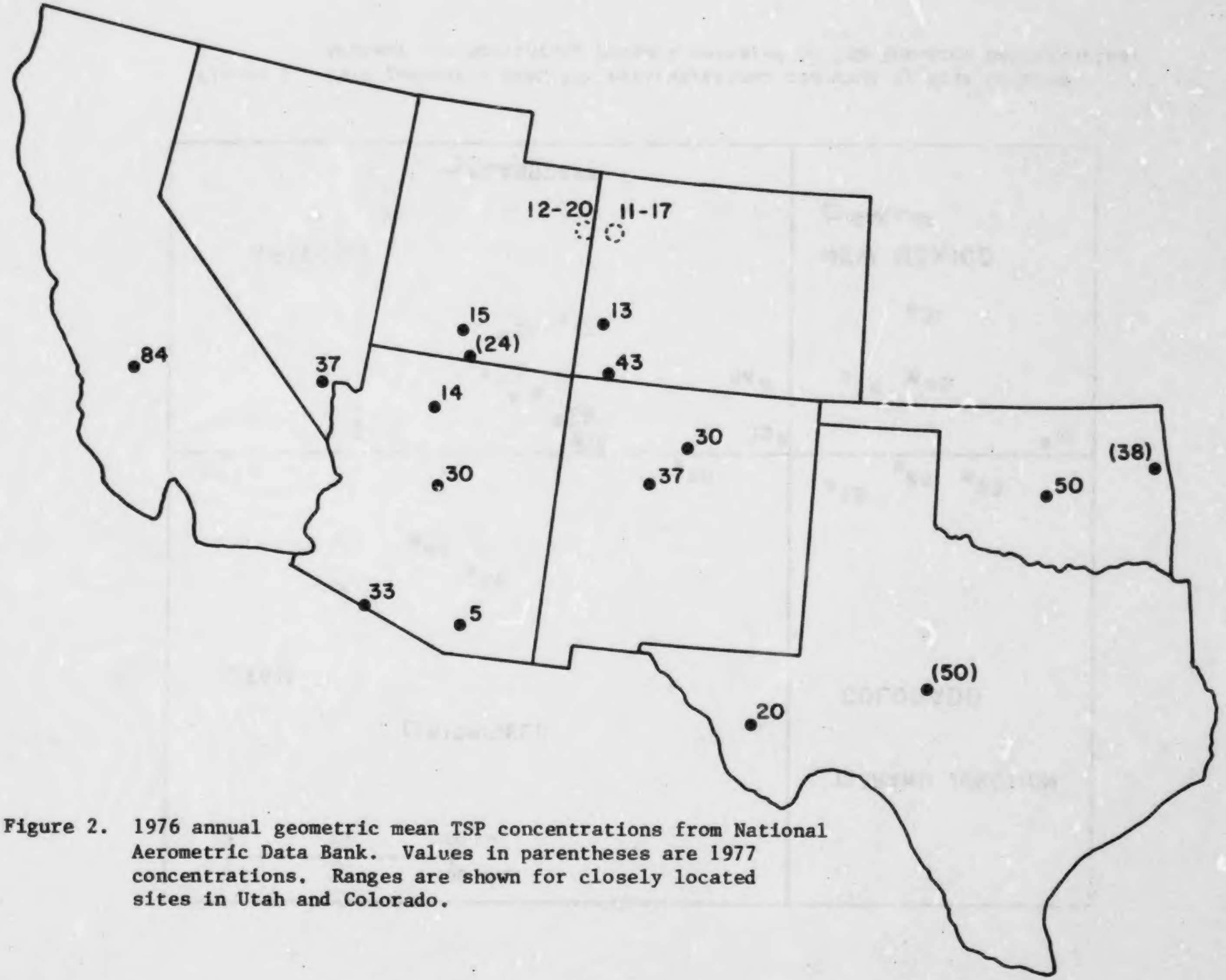

12-20
11-17
15
(24)
13
43
84
37
14
30
30
37
50
(38)
33
5
(50)
20

Figure 2. 1976 annual geometric mean TSP concentrations from National Aerometric Data Bank. Values in parentheses are 1977 concentrations. Ranges are shown for closely located sites in Utah and Colorado.

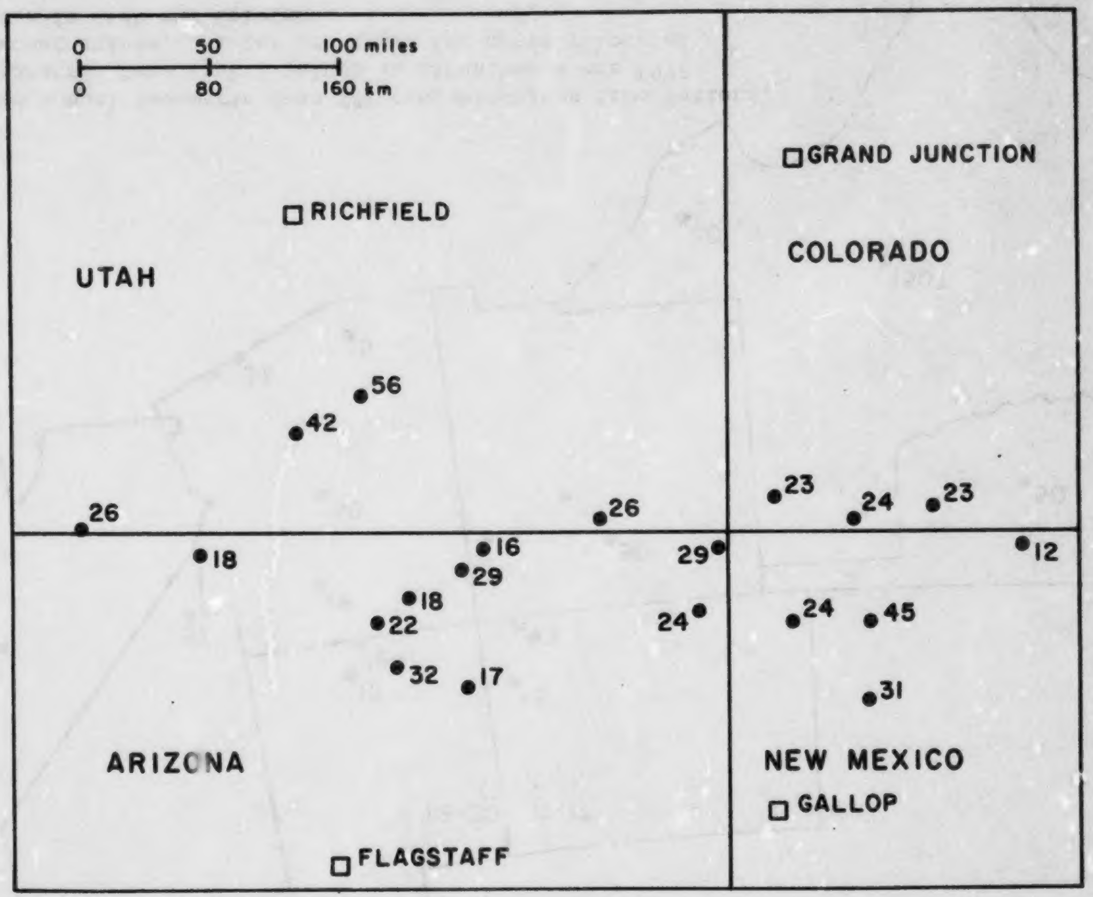

0
50
100 miles
0
80
160 km
RICHFIELD
UTAH
GRAND JUNCTION
COLORADO
56
42
26
26
23
24
23
18
16
29
29
18
22
24
12
24
45
32
17
31
ARIZONA
NEW MEXICO
GALLOP
FLAGSTAFF

Figure 3. 1976 geometric mean TSP concentrations observed by Four Corners Ambient Air Monitoring Network operated by Ute Research Laboratories.

The means shown in Figures 2 and 3 have been combined and summarized as a frequency distribution, Figure 4, that distinguishes the data by site type; i.e., remote or rural. In this sample, on the average, rural sites experienced a mean concentration of 38 μg/m^3 in contrast to the 24 μg/m^3 experienced by remote sites. Because of the small size of the rural-site sample, this difference may not be significant, but it suggests that the impact from rural activities at these sites is in the vicinity of 10-20 μg/m^3.

Estimates of background concentrations can also be obtained directly from a number of particulate studies. Background concentrations, taken from three of these studies are listed in Tables 2, 3 and 4. PEDCo used the data contained in Table 2 to develop the following relationships between vegetative cover in the Southwest and background particulate levels: forest-woodland, 15-20 μg/m^3; southern desert scrub, 25-30 μg/m^3; northern desert scrub, 20-30 μg/m^3; and grassland, 22-27 μg/m^3. The values in Table 3 were used by TRW to determine a weighted average background concentration of 30 μg/m^3 for Phoenix, Arizona. The local health departments suggested 35 μg/m^3 and 25 μg/m^3 as appropriate background values for Las Vegas and Reno, respectively. In addition to these estimates that are based directly on observations, PEDCo estimated background concentrations for sites in Colorado and Utah from the y-intercepts of emission density versus air quality, and modeling analyses. These esitmates are presented in Table 4.

TABLE 2. TSP CONCENTRATIONS AT SELECTED BACKGROUND SITES IN NEW MEXICO, ARIZONA, AND NEVADA

State	Sampling site location	Annual geometric mean, μg/m^3
New Mexico	Albuquerque - NASN	22
	Bernalillo County-Radar Stn.	32
	Dona Ana County	13
	White Rock	32
Arizona	Organ Pipe Cactus Nat'l Monument	26
	Grand Canyon	21
	Davis Dam	29
	Page	17
Nevada	White Pine - NASN	14
	Las Vegas - Marina	35
	Boulder City	30
	Las Vegas - Civil Defense Building	34
	Reno	31

Source: Table 3-7, pg. 3-26, Reference 4.

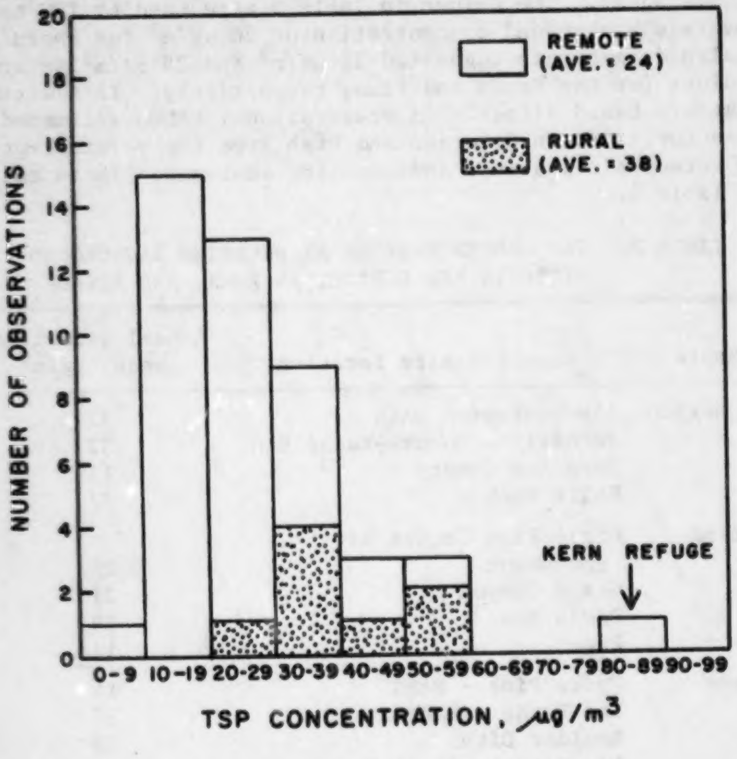


Figure 4. Frequency distribution of annual geometric mean TSP concentrations at 45 rural and remote sites in Southwestern U.S.

TABLE 3. TSP CONCENTRATIONS AT SELECTED BACKGROUND SITES IN ARIZONA

Site	Annual geometric mean, μg/m^3 1973	1974	1975
Grand Canyon	22	17	N/A
Petrified Forest	26	23	N/A
Organ Pipe	34	23	31
Montezuma	28	27	34
Average	28	23	32

Source: Table 4-1, pg. 4-1, Reference 3.

TABLE 4. ESTIMATED BACKGROUND TSP CONCENTRATIONS FOR SELECTED AQCR's IN COLORADO AND UTAH

State	AQCR	Estimated annual geometric mean μg/m^3
Colorado	Denver	40-45
	Pawnee	45
	San Isabel	
	Colorado Springs	30-35
	Pueblo	45
	Other sites	40-45
	Yampa	20
	Grand Mesa	40
Utah	Wasatch Front	40

Source: Table 2-2, pg. 2-8, Reference 12.

Twenty-four Hour Concentrations

Figures 5 and 6 display the second highest 24-hour TSP concentrations for 1976 in the same fashion used for the geometric means. Again, substituted 1977 concentrations are indicated by parentheses, and a range of values is given for samplers in geographic proximity. In Figure 5, one concentration exceeds the primary standard and five others exceed the secondary standard, with two of the five being observed in northwestern Colorado. In Figure 6, two concentrations exceed the primary standard and nine others exceed the secondary standard.

These 24-hour, second-highest, concentrations have been combined as a single frequency distribution in Figure 7a. In this case, there appears to be no significant difference between the averages shown at rural and remote stations. A similar frequency distribution of the maximum 24-hour concentrations has been plotted in Figure 7b, and again there appears to be no tendency for the highest concentrations to occur more frequently at rural stations than at remote stations.

Finally, inspection of the two sets of maps reveals no obvious relationship between geometric means and the magnitude of the second-highest 24-hour concentration. The lack of strong relationship was confirmed by a linear correlation between the two sets of data of 0.42. Although this is significant at the 0.01 level with 45 pairs, only 17 percent (R^2) of the variation is common.

CHARACTERISTICS AND SOURCES

An understanding of the physical and chemical nature of background particulates provides insight into their probable sources and likely transport distances. This discussion briefly reviews particle-size distribution information and some of the generally accepted concepts pertaining to the generation of wind-blown desert dust. It also summarizes the results of recent studies that have investigated the chemical species present in desert dust and interrelationships among these species. Much of this latter work was carried out on samples collected at the Research Ranch approximately 60 miles to the southeast of Tucson, Arizona.

Particle Size Distribution

Very few measurements covering the complete size range of particles collected by the standard high-volume sampler have been reported in the literature for desert atmospheres. Furthermore, it is rather widely conceded that the details of observed distributions are dependent upon the collection devices and experimental techniques employed. (See Lundgren and Paulus,[13] and Farmer and Hornkohl,[14] for example). Nevertheless, recent studies have contributed substantially to knowledge of airborne particulates in a variety of environments, and this information can be used to supplement the limited desert measurements to obtain the most significant features of particle size distributions in background, desert atmospheres.

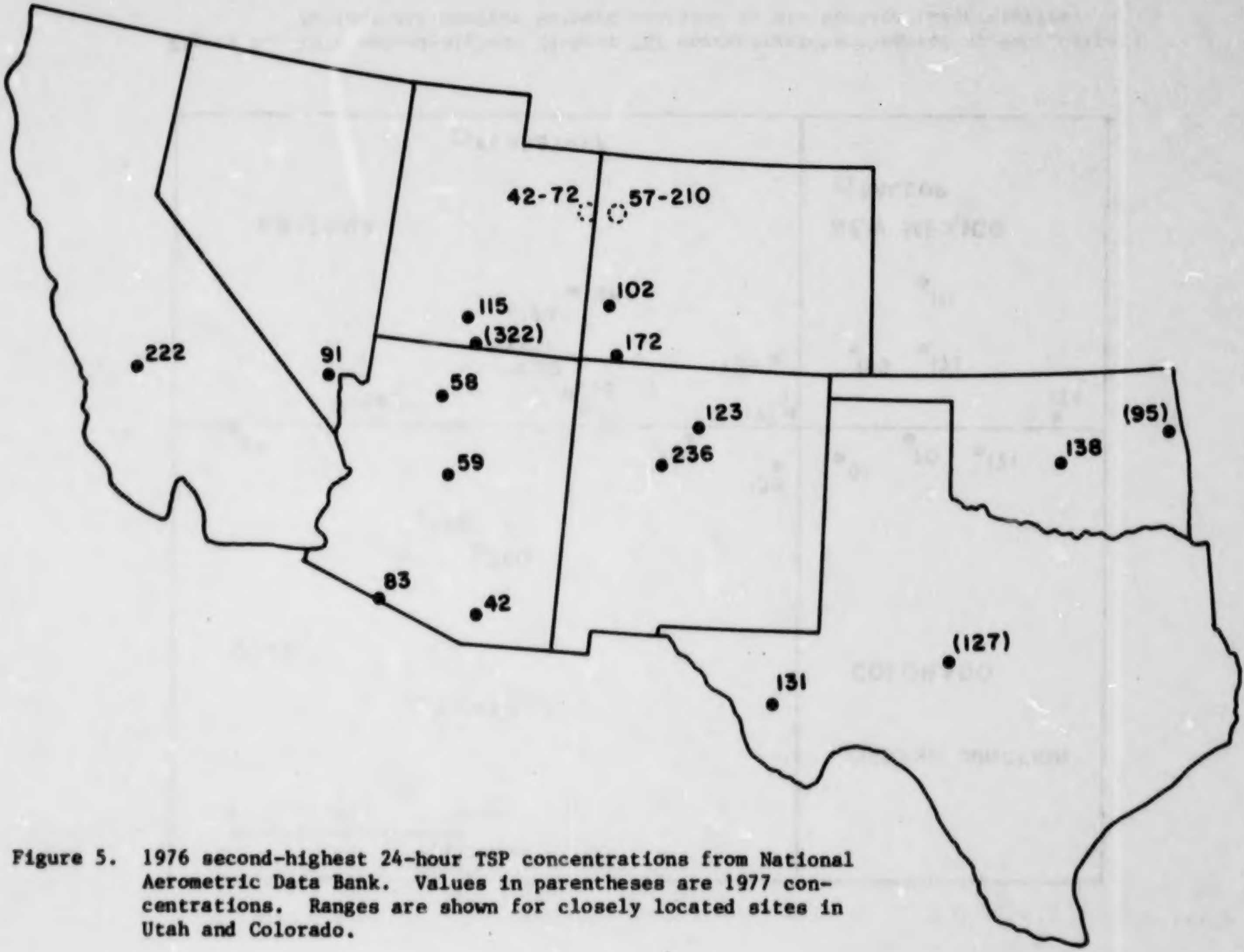

42-72
57-210
102
115
(322)
172
222
91
58
123
236
(95)
138
59
83
42
(127)
131

Figure 5. 1976 second-highest 24-hour TSP concentrations from National Aerometric Data Bank. Values in parentheses are 1977 concentrations. Ranges are shown for closely located sites in Utah and Colorado.

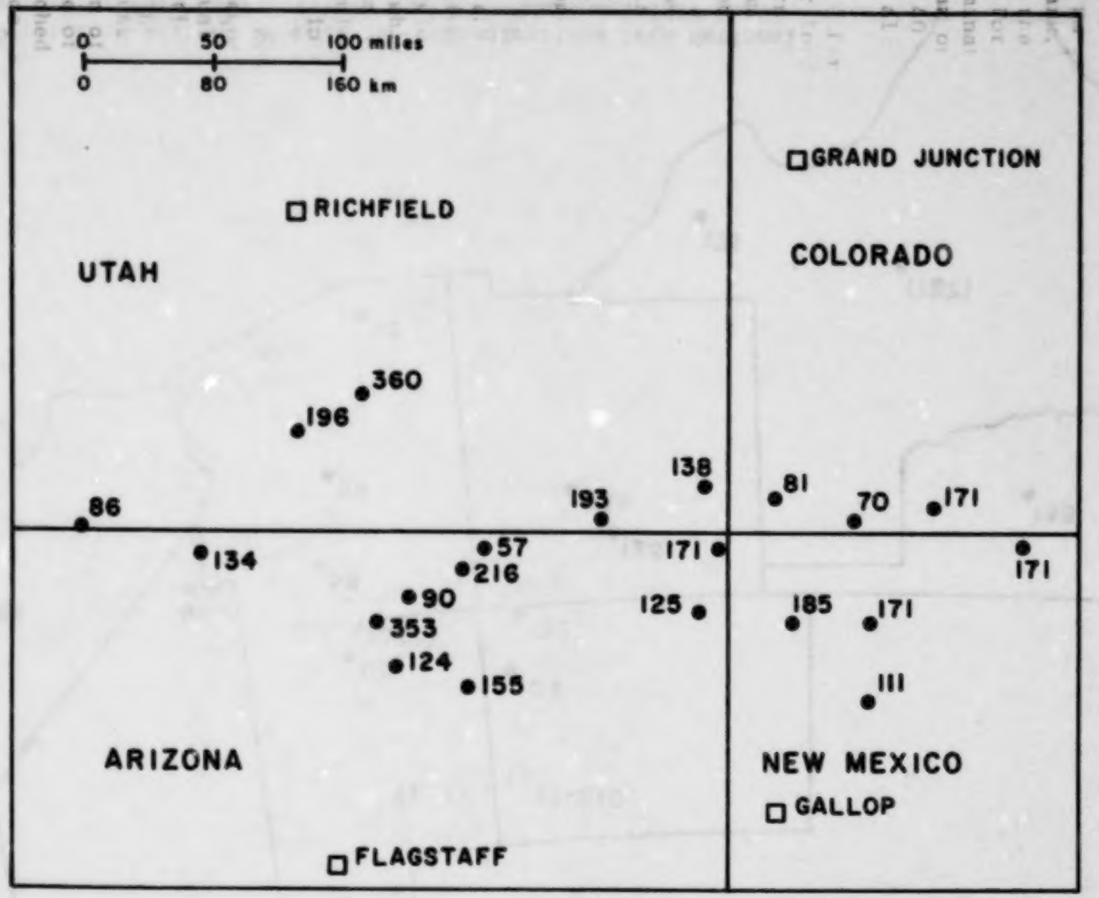
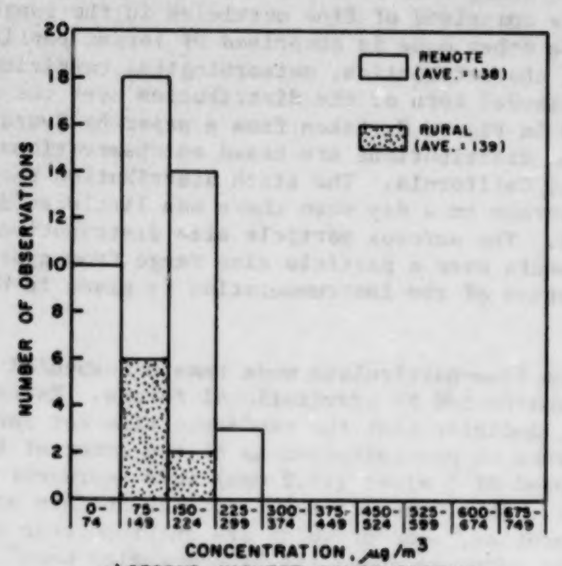
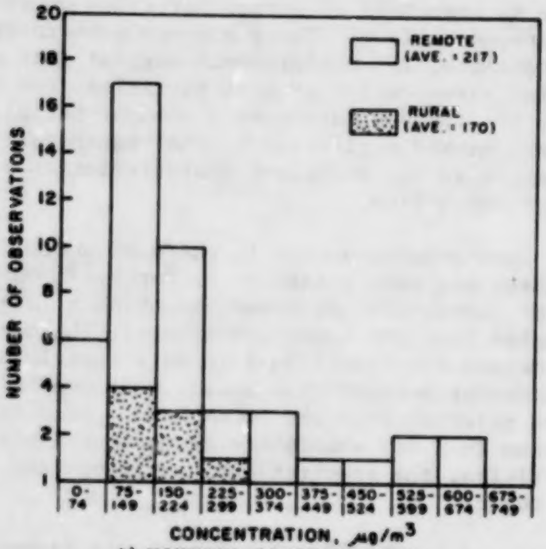

0
50
100 miles
0
80
160 km
RICHFIELD
GRAND JUNCTION
UTAH
COLORADO
360
196
86
138
193
81
70
171
134
57
216
90
353
124
155
171
125
185
171
171
111
ARIZONA
NEW MEXICO
GALLOP
FLAGSTAFF

Figure 6. 1976 second-highest 24-hour TSP concentrations observed at Four Corners Ambient Air Monitor Network operated by Ute Research Laboratories.



a) SECOND HIGHEST CONCENTRATION



b) MAXIMUM CONCENTRATION

Figure 7. Frequency distributions of 24-hour TSP concentrations at 45 rural and remote sites in Southwestern U.S.

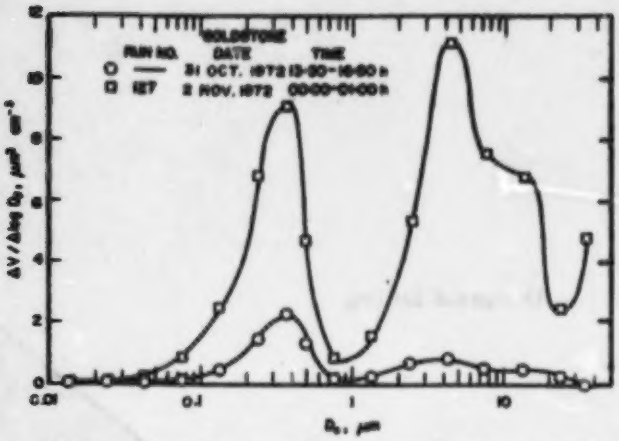
The picture that emerges is of a volume, or mass, distribution that is bimodel. One mode is comprised of fine particles in the range from 0.1 μm to roughly 2 μm, and the other mode is comprised of larger particles, with a peak that depends on soil characteristics, meteorological conditions and height above ground. The bimodel form of the distribution over the range from 0.1 to 10 μm is illustrated in Figure 8, taken from a paper by Sverdrup, Whitby and Clark.[15] Five of the distributions are based on observations made at Goldstone in the Mojave Desert, California. The sixth distribution represents conditions at Fort Collins, Colorado on a day when there was little evidence of local contamination from dust. The aerosol particle size distribution was measured with four on-line instruments over a particle size range from approximately 0.003 to 40 μm. A description of the instrumentation is given in Whitby et al.[16]

Particles in the fine-particulate mode remain suspended in the atmopshere for long distances unaffected by gravitational forces. Estimates by Esmen and Corn,[17] for example, indicate that the residence time for particles 1 μm in diameter in the absence of precipitation is of the order of 100 hours. At an average transport speed of 5 m/sec (11.2 mph) this represents a travel distance of 1800 km (1118 mi). Thus, many of the particles in this mode reflect emissions from distant sources, some of which are anthropogenic and others natural. This fine particulate mode was named the "accumulation mode" by Willeke and Whitby[18] to reflect the fact that aerosol particles that grow into this range from smaller sizes by coagulation or condensation tend to remain in this size range.

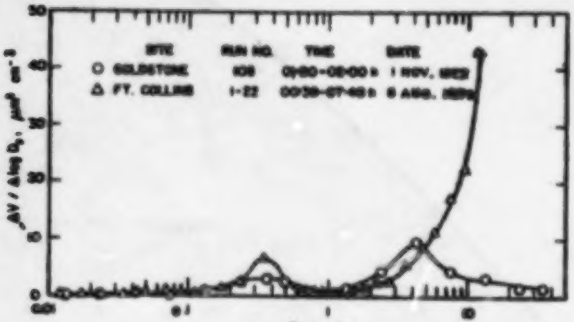
The other mode is comprised of larger particles whose primary source is the underlying ground surface. Under average meteorological conditions and uniform surface conditions, TSP measurements suggest that a quasi steady state develops in which the resuspension of soil particles from the desert floor is roughly balanced by the removal rate over a 24-hour period. During any 24-hour period, however, marked variations in the resuspension rate occur as a result of major changes in the turbulent characteristics of the wind field and in the amount of convection.

Evidence that resuspension occurs in puffs of short duration (less than or equal to 2 minutes) has been presented by Porch.[19] Dust devils are a visual indication of convective adjustment in which a large size range of particles are injected into the lower atmosphere. The next section discusses the generation processes for desert dust in more detail, but common experience illustrates relationships between wind speed, soil conditions and the injection of particulate material into the atmosphere. Once injected, the residence time of the particles in a dry atmosphere depends upon the initital height reached by the particles, the gravitational settling rate, atmospheric turbulence, and ground cover.

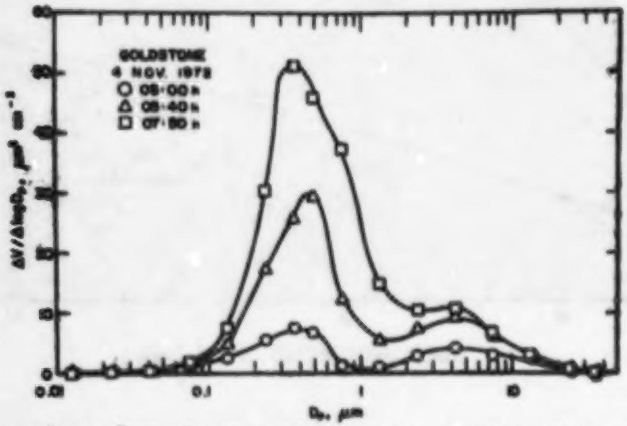
Figure 9, developed by MRI,[20] relates particle diameter to three settling/suspension regimes at wind speeds up to 18 mph. The area labeled "suspension" represents particles that have the potential for long range transport. The area labeled "unimpeded settling" represents particles with terminal velocities sufficient to largely overcome the effects of turbulence and horizontal transport. Particles in the "impeded settling" area respond to atmospheric motions while settling.



A comparison of the background volume distributions during a very clean period and an evening with higher total volume.



A comparison of the volume distributions of background aerosols sampled at Goldstone and Fort Collins, Colorado.



Incursion of aged aerosol from the south coast basin.

Figure 8. Volume distributions observed in the Mojave Desert, California, and Fort Collins, Colorado (from Sverdrup, Whitby, and Clark,[15] pp. 489 and 490).

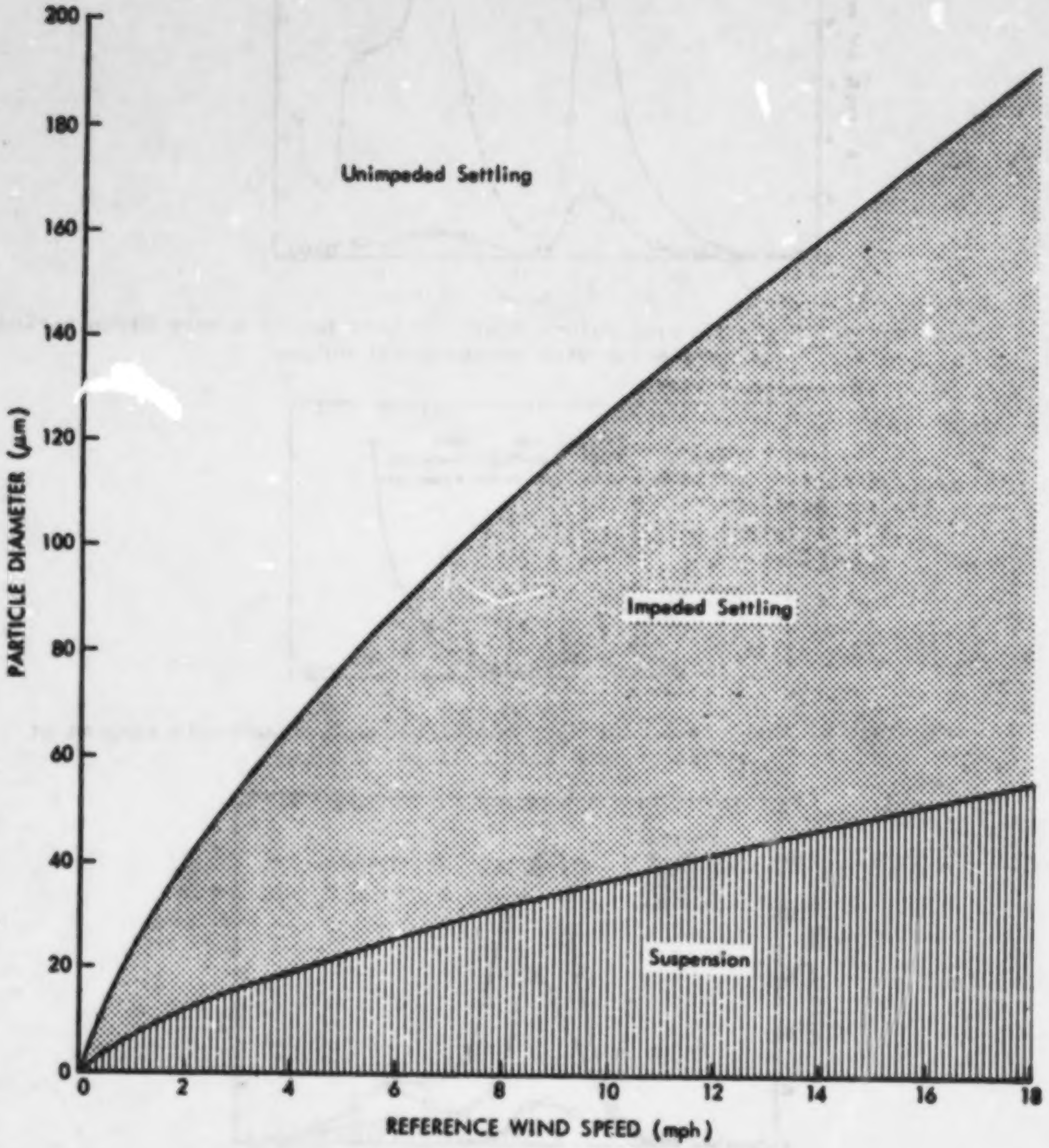


Figure 9. Particle settling/suspension regimes.[20]

Because of the complicated relationships alluded to above, the modal peak due to ground level sources can be expected to vary with desert location and sampling height. An example of the shift in the peak toward greater particle diameter as the sampling height decreased from 30 m to 0.3 m is shown in Figure 10 taken from Schmel.[21] (Derivations of the lines "A" and "B" are given in Schmel's paper). The observations used in preparing this figure were made during a dry, spring period in a semi-arid and sparsely vegetated region of the Atomic Energy Commission's Hanford reservation. The upwind terrain was undisturbed for several miles and included a region without sage bush that extended about 200 feet upwind. Particles in the respirable size range were determined using 20 cfm cascade particle impactors; the larger particles were collected by deposition within a wind-direction self-orienting attachment to the impactors.

Generation of Wind-blown Dust

The generation of dust begins at a wind speed great enough for aerodynamic forces to overcome the forces holding individual particles in the soil. Although a considerable amount of theoretical and experimental work has been carried out on idealized systems (see for example, Chepil,[22] Greeley et al,[23] Marshall[24] and Lyles and Allison[25]), few studies of wind-generated fugitive dust have addressed natural soil surfaces and man's impact upon these surfaces. As a result, current understanding of the mechanisms by which desert soil becomes entrained is largely qualitative.

Two important aspects of soil structure are the distribution of particle sizes and the aggregate structure of the soil. The undisturbed desert soil surfaces in much of the southwest are composed of a silt aggregate and a thin crust of gravel and sand, (see Richard et al.[1] for a description of soil characteristics in the Phoenix area). This surface crust is sometimes referred to as the desert pavement. It is easily broken up by human activities and is particularly vulnerable to vehicular travel. Where loose sand particles exist, moderate wind speeds may be sufficient to initiate sandblasting of the surface soil, resulting in the release of soil fines and the suspension of particulates.

Under sufficiently strong winds, severe dust storms may develop, particularly in regions where the soil surface has been disturbed as a result of man's activities. For example, on February 23, 1977 central Oklahoma experienced the worst dust storm in more than 20 years with 24-hour average TSP concentrations up to 5800 $\mu g/m^3$.[26] The paths of dust were clearly evident in photographs prepared from satellite data. Reported surface winds were 30 to 40 knots in the dust swaths and 20 to 30 knots in the clear area. Oklahoma had another severe storm on March 2, 1977. The photographs show very strikingly that in each case the western limit of the dust coincides approximately with the Texas-New Mexico border, apparently because of changing soil characteristics and agricultural practice in the vicinity of the border. Rangeland is predominant on the New Mexico side of the border, and cropland on the Texas side.

Dust storms are typically associated with sustained wind speeds of 20 to 30 knots produced by major weather systems. In a study of dust storms in the

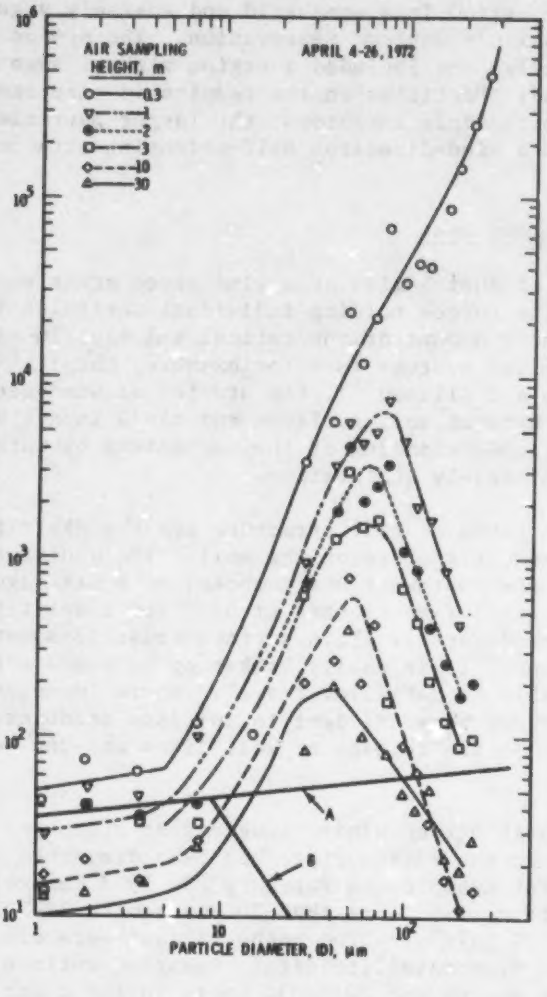


Figure 10. Volume distribution as a function of height.[21]

Great Plains,[27] Hagen and Woodruff found that the average duststorm lasted 6.6 hours and the median concentration during the period of the storm was 4850 $\mu g/m^3$. In this study, particulate concentrations were calculated from National Weather Service visibility data using the relationship

$$C_6 = \frac{56.0}{V^{1.25}} \text{ mg m}^{-3}$$

developed by Chepil and Woodruff.[28] In this expression C_6 is the dust concentration 6 feet above the surface and V is the horizontal visibility in kilometers. The data analyzed for each station were from 10-year period beginning in either 1949 or 1950. In a related study, Hagen and Woodruff[29] roughly estimated that the median size of the duststorm covered an area of about 188 × 188 miles square. The average number of days per year with dust reported at 19 stations distributed throughout Texas, New Mexico, Oklahoma and Colorado ranged from 1.3 at Grand Junction, Colorado to 47.5 at Lubbock, Texas. The mass median particle diameter during duststorms has been reported by Whitby et al[30] as 50 μm.

Chemical Constitutents

The information provided here has been taken largely from a paper by Korte and Moyers[31] that describes the results of a measurement program conducted between September 1975 and October 1976 at the Research Ranch. The Research Ranch is a protected land laboratory comprising 7,840 acres of private, state and federal land, generally high desert grassland. It is situated in the transition zone between the Sonoita Plains and the Hauchuca Mountains. The nearest town is Elgin (population 50) approximately 5 miles to the north.

Thirty-two size fractionated samples were collected during the sampling period as part of a larger program described by Moyers et al.[2] Sampling was performed using Sierra 230 two-stage, high-volume slotted Cascade Impactors. Particle separation using this system was about 2 μm aerodynamic diameter. Elemental analysis was performed on digested filters by atomic absorption spectrometry. Analyses for ammonium, nitrate and sulfate ions were also carried out.

The data were evaluated using statistical correlations, particle size distributions, and comparison of particle composition with the composition of suspected source materials. In calculating the crustal enrichment factor, aluminum was chosen as the reference element since soil is considered to be the sole source of aluminum in this region.

It is concluded on the basis of this and the previous work by Moyers et al that wind blown soil materials dominate the mass concentration of large particles (greater than 2 μm) and all measured species except Cd, Zn, Pb, Cu, $SO_4^=$, NO_3^- and NH_4^+. On the other hand, the smaller particles are composed of soil material, gaseous oxidation products, and species apparently from distant anthropogenic or natural sources. The small particle sulfate, nitrate, and ammonium ions are the result of gas-to-particle conversion from gaseous SO_2, NO_x, and NH_3 released into the atmopshere from natural sources such as decaying vegetation, and anthropogenic sources such as smelters, agriculture, power plants and urban areas. Previous work by Moyers et al[32] estimated that the contribution of soil material to the total atmospheric burden of particulate matter at the Research Ranch is 50 percent.

Figures 11 and 12 taken from the paper by Korte and Moyers,[31] and the linear correlation coefficients calculated between chemical species that are presented in the paper, support these conclusions. Figure 11 shows the percentage distribution of the individual species on the respirable (less than 2 μm) particles, while Figure 12 is a plot of the crustal enrichment factors for the respirable particles. Species with enrichment factors near unity (from 0.5 to 5) are attributed to airborne soil material, while species with enrichment factors greater than about 50 are attributed to sources other than the injection of crustal weathering products into the atmosphere.

More general information concerning the magnitude and distribution of sulfates and nitrates is being obtained from an expanded monitoring network of high-volume samplers within the Western Energy Resource Development Area.[33] Preliminary summaries of data, collected before major expansion of the network occurred, show sulfate concentrations in the 1 to 3 μg/m^3 range in northern Arizona, southern Utah, northwestern New Mexico, and southeastern Colorado. With the exception of southern Arizona where values from 3 μg/m^3 to greater than 15 μg/m^3 were reported, the region lies in the range from 1 to 6 μg/m^3. This is in agreement with the mean value of 2.6 μg/m^3 reported for rural areas in the West by Greeley et al[34] and Altshuller.[35] Better definition of regional differences will be available from the expanded network. Nitrate data from the early network is less complete and shows greater variability than the sulfate data. Mean values generally range from 1 to 5 μg/m^3 throughout the region, with the lower values being found in the rural areas.

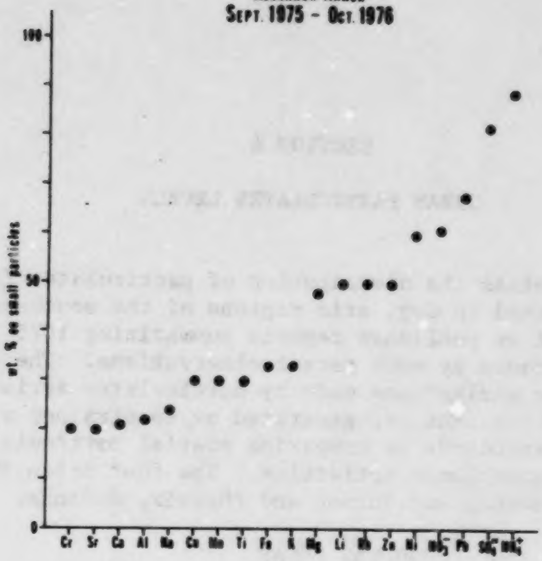


Figure 11. Percentage distribution of measured chemical species on respirable particles in the atmosphere at the Research Ranch. (Korte and Moyers[31])

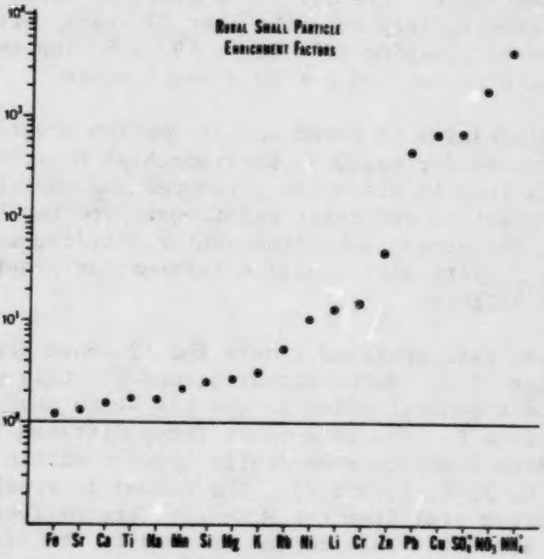


Figure 12. Crustal enrichment factors of species measured on respirable particles in the atmosphere at the Research Ranch. (Korte and Moyers[31])

SECTION 4

URBAN PARTICULATES LEVELS

This section examines the distribution of particulates in and around four major urban areas located in dry, arid regions of the southwest. The review is based in large part on published reports summarizing 1975 TSP data, but is supplemented in some cases by more recent observations. The objective is to analyze the relative contributions made by particulates arriving from outside the urban area, and those that are generated or reentrained within the area to violations of the standards by comparing spatial particulate patterns with land usage and associated human activities. The four urban areas studied are Las Vegas and Reno, Nevada, and Tucson and Phoenix, Arizona.

PARTICULATE LEVELS IN AND AROUND LAS VEGAS

Las Vegas is situated near the center of a broad desert valley which runs from northwest to southeast. The valley floor slopes gradually upward on each side towards the surrounding mountains. The climate is charactrized by low humidity, abundant sunshine, mild winters and hot dry summers. The prevailing winds at McCarran Airport, 7 miles south of downtown Las Vegas are from the west through south-southwest. Precipitation averages about 4 inches per year. Las Vegas has grown very rapidly over the last 20 years, with the population of the metropolitan area reaching 361,100 in 1977.[36] The tourist industry dominates. Agriculture is carried out on a small scale.

The following discussion is based on information provided in a 1977 report by PEDCo[5] prepared for the U.S. Environmental Protection Agency. In this report, TSP data from 12 sites are presented and analyzed. Figure 13 shows the sampling locations and their relationship to Las Vegas. In terms of physical setting, the sites range from center city/commercial to rural/recreational. Table 5 lists site location information provided in the PEDCo report, plus monitor heights.

The concentration data analyzed covers the 12-month period from October 1974 through September 1975. Mean concentrations for this period are plotted against distance from a central point in the Las Vegas business district (CBD), Fire Station No. 1, Site E. The data cover three distance intervals. The first interval contains 5 monitors centrally located within the heart of the urban area. (Sites C, I, F, H, and E). The second interval contains 4 monitors that ring the urban area from the McCarran International Airport to the south to the Nellis Air Force Base to the northeast; the distances of these monitors from Site E range from about 10 to 14 km. The third interval contains 3 monitors located from 20 to 24 km from Site E. As shown in Figure 14, two of these monitors (B and D) are located within the city of Henderson (1977

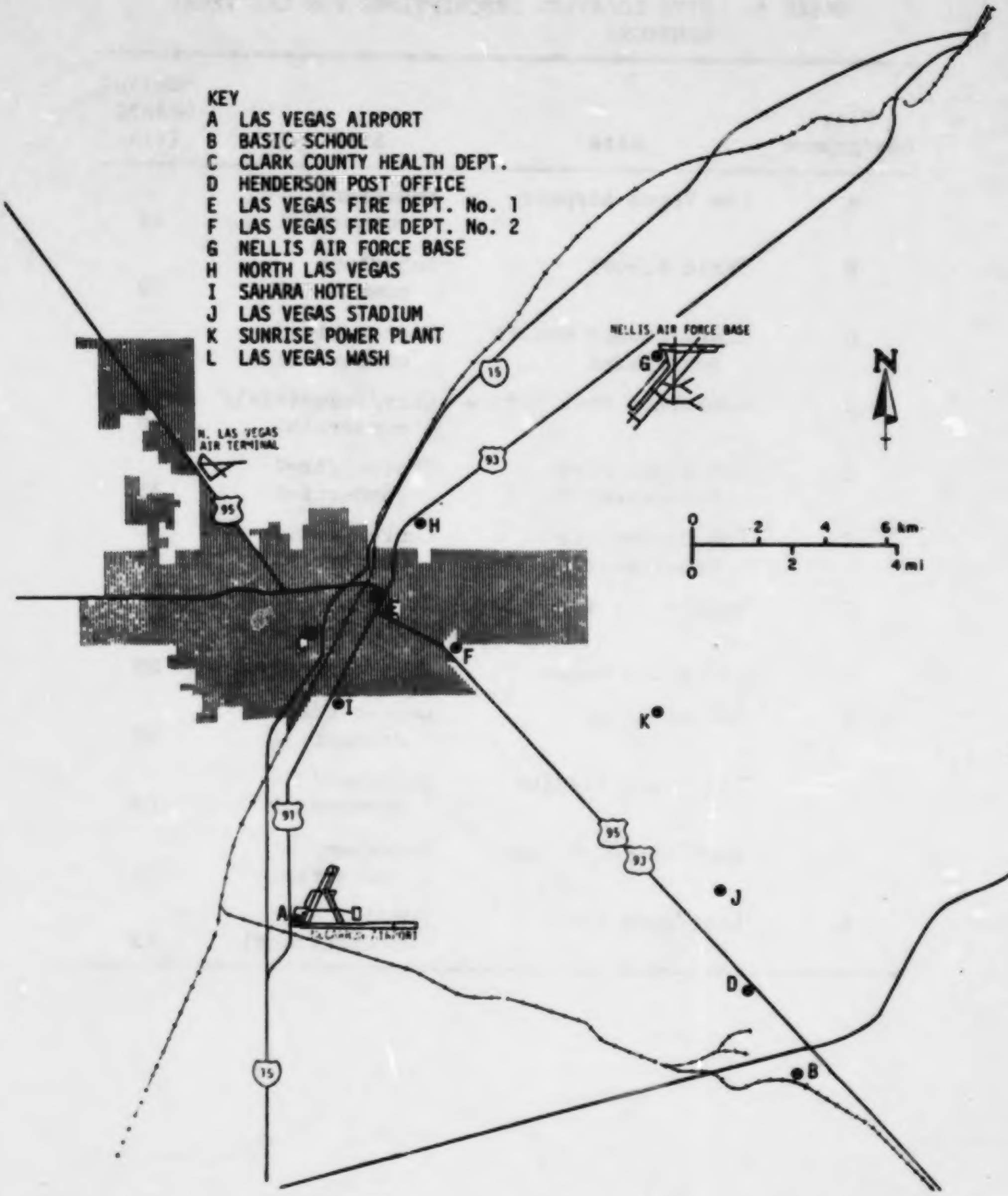

KEY
A LAS VEGAS AIRPORT
B BASIC SCHOOL
C CLARK COUNTY HEALTH DEPT.
D HENDERSON POST OFFICE
E LAS VEGAS FIRE DEPT. No. 1
F LAS VEGAS FIRE DEPT. No. 2
G NELLIS AIR FORCE BASE
H NORTH LAS VEGAS
I SAHARA HOTEL
J LAS VEGAS STADIUM
K SUNRISE POWER PLANT
L LAS VEGAS WASH
NELLIS AIR FORCE BASE
N. LAS VEGAS AIR TERMINAL
N
0 2 4 6 km
0 2 4 mi
15
93
95
91
A
B
C
D
E
F
G
H
I
J
K
L

Figure 13. The Clark County APCD sampling network for TSP (after PEDCo).[5]

TABLE 5. SITE LOCATION DESCRIPTIONS FOR LAS VEGAS MONITORS

Site designator	Site	Site type	Monitor height (ft)
A	Las Vegas Airport	Suburban/ commercial	25
B	Basic School	Suburban/ commercial	30
C	Clark County Health Department	Center city/ commercial	25
D	Henderson Post Office	City/industrial/ commercial	30
E	Las Vegas Fire Department No. 1	Center city/ commercial	35
F	Las Vegas Fire Department No. 2	Center city/ commercial	25
G	Nellis Air Force Base	Suburban/ commercial	25
H	North Las Vegas	City/commercial	25
I	Sahara Hotel	Center city/ commercial	30
J	Las Vegas Stadium	Suburban/ commercial	10
K	Sunrise Power Plant	Suburban/ industrial	25
L	Las Vegas Wash	Rural/ recreational	25

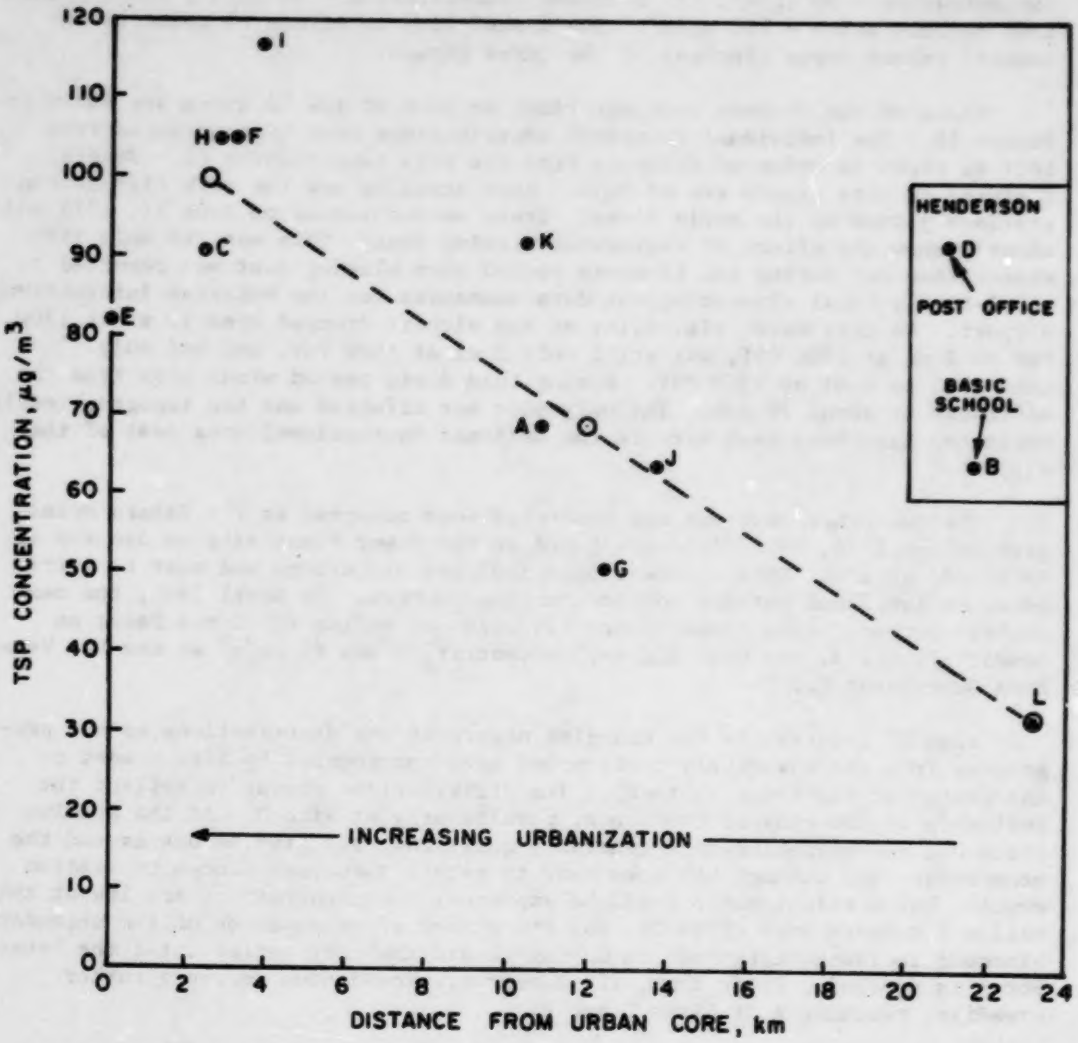


Figure 14. Annual mean TSP concentrations versus distance from urban core (Las Vegas).

population of 20,100)[36] southeast of Las Vegas. These monitors are therefore subject to particulates generated by activities within that city. Eliminating these two monitors, and averaging the concentrations within the other two intervals gives the following results as one approaches the Las Vegas CBD from the largely undisturbed rural/recreational area to the east: (1) background concentration - 32 $\mu g/m^3$, (2) outlying concentration - 69 $\mu g/m^3$, and (3) downtown concentration - 100 $\mu g/m^3$. The dashed line in Figure 14 connects the central values (open circles) of the three groups.

Plots of the 24-hour concentrations at each of the 12 sites are shown in Figure 15. The individual frequency distributions have been arranged from left to right in order of distance from the city center (Site E). Several features of this figure are of note. Most striking are the very high concentrations joined by the solid lines. These were observed on June 17, 1975 and clearly show the effect of regionwide blowing dust. This was the only TSP observation day during the 12-month period when blowing dust was reported in the 3-hourly local climatological data summaries for the McCarran International Airport. On this date, visibility at the airport dropped from 20 mi at 1300 PST to 2 mi at 1600 PST, was still only 2 mi at 1900 PST, and had only increased to 4 mi by 2200 PST. During this dusty period winds blew from the southwest at about 20 mph. The only site not affected was the topographically protected Las Vegas Wash site in the National Recreational Area east of the city.

The two other most extreme concentrations occurred at the Sahara Hotel site on April 24, 1975 (895 $\mu g/m^3$) and at the Power Plant site on January 12, 1975 (793 $\mu g/m^3$). Both of these were isolated violations and must be attributed to local and perhaps non-reoccurring sources. On April 24th, the next highest concentration observed was 129 $\mu g/m^3$ at Nellis Air Force Base; on January 12, 1975, the next highest concentration was 87 $\mu g/m^3$ at the Las Vegas Fire Department No. 2.

Also of interest is the changing nature of the distributions as one progresses from the relatively undisturbed area represented by Site L west to the center of Las Vegas (Site E). The distributions appear to reflect the influence of the city of Henderson, particularly at Site D. At the Stadium (Site J), concentrations are generally quite low, but five values exceed the standards. (No attempt has been made to relate these exeedances to stadium events, but a relationship could be expected). Concentrations are low at the Nellis Air Force Base (Site G), but the number of exceedances of the secondary standard increase thereafter in moving toward the city center until the Sahara Hotel is reached. After that, the number of exceedances decrease rather steadily, reaching 6 at Sites C and E.

It is tempting to associate the improvement in air quality as one progresses inward toward the CBD from the Sahara Hotel with a decrease in fugitive dust emissions from disturbed soil surfaces, unpaved roads, and the like, and this may well be the case. Such a hypothesis does not agree well with the emission densities determined by PEDCo for the various sites, as shown in Table 6, however.

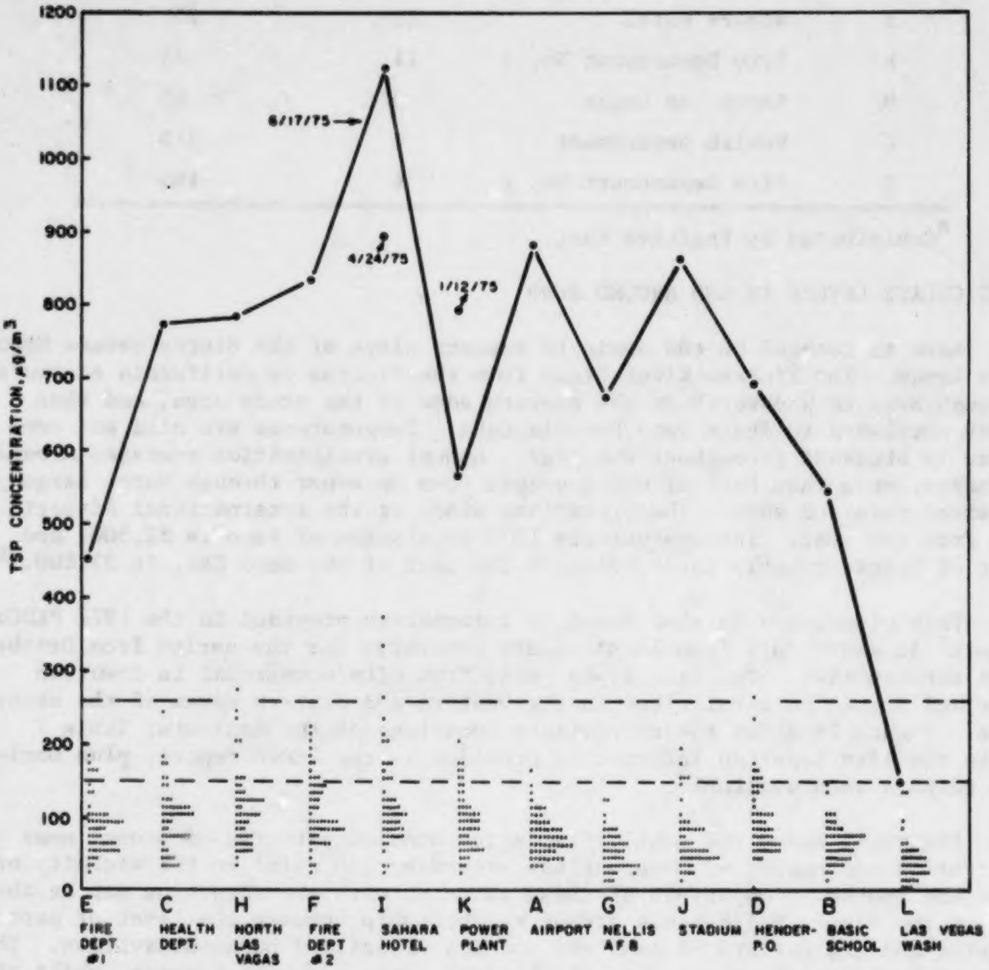


Figure 15. Plots of 24-hour TSP concentrations at 12 sites ordered by distance from city center (Las Vegas).

TABLE 6. NUMBER OF EXCEEDENCES OF THE SECONDARY STANDARDS AND EMISSION DENSITIES AT SELECTED SITES

Site designator	Site	Number of exceedences	Emission density[a] (tons/mi^2/day)
I	Sahara Hotel	15	251
F	Fire Department No. 2	11	75
H	North Las Vegas	9	85
C	Health Department	6	210
E	Fire Department No. 1	6	163

[a] Contributed by fugitive dust.

PARTICULATE LEVELS IN AND AROUND RENO

Reno is located on the semiarid eastern slope of the Sierra Nevada Mountain Range. The Truckee River flows from the Sierras in California eastward through Reno to Wadsworth on the eastern edge of the study area, and then turns northward to drain into Pyramid Lake. Temperatures are mild and sunshine is abundant throughout the year. Annual precipitation averages around 7 inches, more than half of which occurs from December through March largely as mixed rain and snow. The prevailing winds at the International Airport are from the west. The approximate 1977 population of Reno is 82,500, and that of Sparks roughly three miles to the east of the Reno CBD, is 33,800.[36]

This discussion is also based on information provided in the 1977 PEDCo report[5] in which data from 12 sites are presented for the period from October 1974 through 1975. The site types range from city/commercial in downtown Reno and Sparks to rural sites on the western and eastern edges of the study area. Figure 16 shows the approximate locations of the monitors; Table 7 lists the site location information provided in the PEDCo report, plus monitor heights when available.

Figure 17 shows the similarity in the spatial patterns of annual mean concentration and number of observations exceeding 150 $\mu g/m^3$ in the vicinity of Reno and Sparks. Comparison of these patterns with the site-type map at the top of the figure indicates a strong relationship between the level of particulates and the pattern of land use and its associated human activities. The highest concentrations occur in the busiest, most commercial areas, while the lowest concentrations occur in the suburban/residential areas to the west. Farther to the west at Lake Tahoe and Verdi, the mean concentrations were 22 and 18 $\mu g/m^3$, respectively. Concentrations for different site types can be generalized as follows: background concentration (Sites I and J), 20 $\mu g/m^3$; suburban/residential and rural (Sites C, E, F, and L), 46 $\mu g/m^3$; suburban/residential/commercial (Site G), 58 $\mu g/m^3$; and city/commercial and suburban/commercial (Sites B, H and A, D), 77 $\mu g/m^3$. On 15 of the 61 sampling days during the 12-month period, concentration exceeded 150 $\mu g/m$ at one or more of the Reno-Sparks sites. Table 8 lists the concentrations observed at the 9 sites on each of these days. On 8 of the 15 days, the concentration

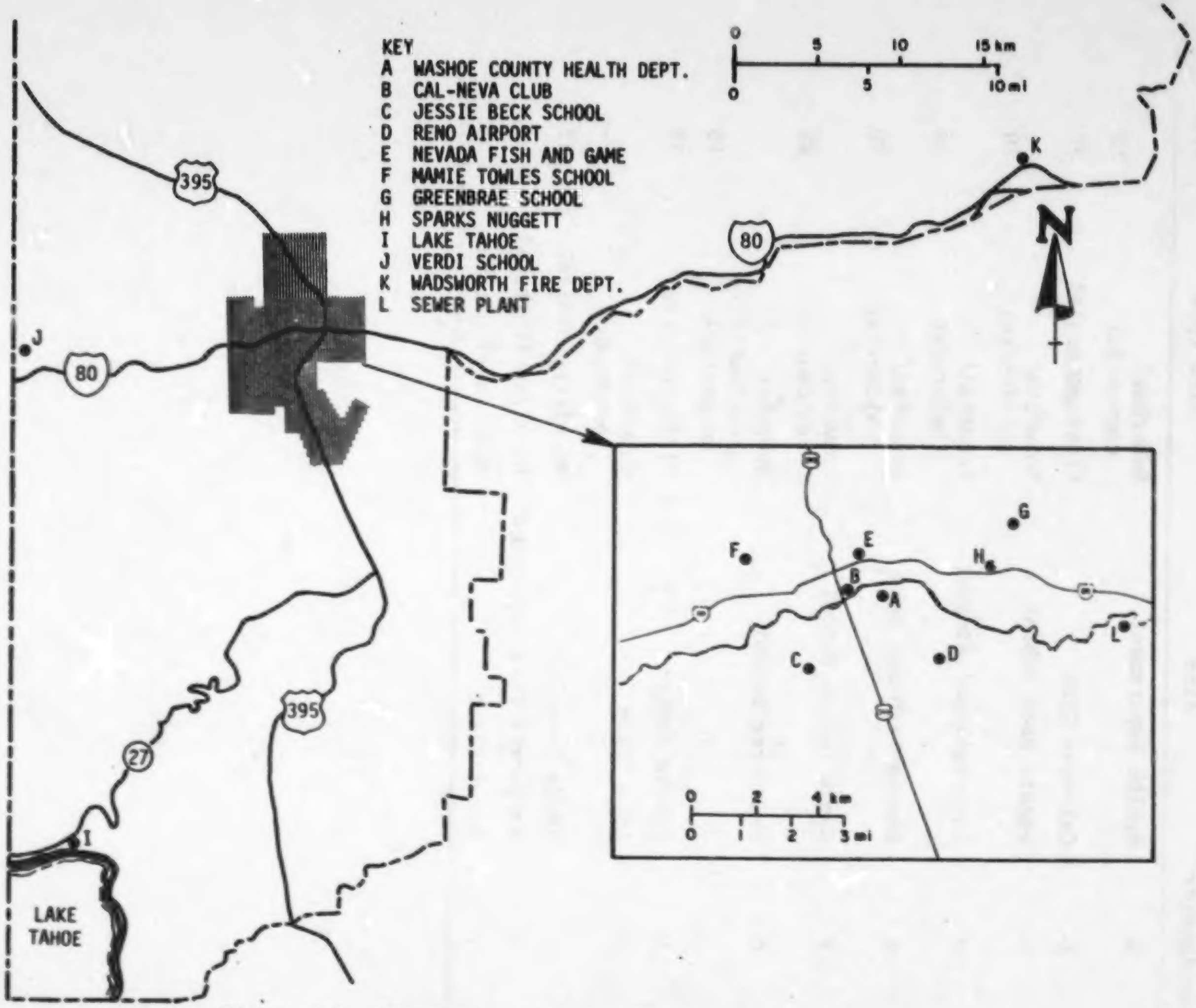

KEY
A WASHOE COUNTY HEALTH DEPT.
B CAL-NEVA CLUB
C JESSIE BECK SCHOOL
D RENO AIRPORT
E NEVADA FISH AND GAME
F MAMIE TOWLES SCHOOL
G GREENBRAE SCHOOL
H SPARKS NUGGETT
I LAKE TAHOE
J VERDI SCHOOL
K WADSWORTH FIRE DEPT.
L SEWER PLANT
0
5
10
15 km
0
5
10 mi
395
80
27
N
LAKE TAHOE
J
K
I
F
E
B
A
C
D
G
H
L
0
2
4 km
0
1
2
3 mi

Figure 16. The Washoe County DEP sampling network for TSP (after PEDCo[5]).

TABLE 7. SITE LOCATION DESCRIPTIONS FOR RENO MONITORS

Site designator	Site	Site type	Height of monitor (ft)
A	Health Department	Suburban/ commercial	15
B	Cal-Neva Club	City/commercial	50
C	Jessie Beck School	Suburban/ residential	20
D	International Airport	Suburban/ commercial	15
E	Nevada Fish and Game	Suburban/ residential	20
F	Mamie Towles School	Suburban/ residential	20
G	Greenbrae School	Suburban/ residential/ commercial	15
H	Sparks Nugget	City/commercial	35
I	Lake Tahoe	Suburban/ commercial	--
J	Verdi School	Rural/residential	15
K	Wadsworth Fire Department	Rural/agricultural	--
L	Sewer Plant	Rural/agricultural	35

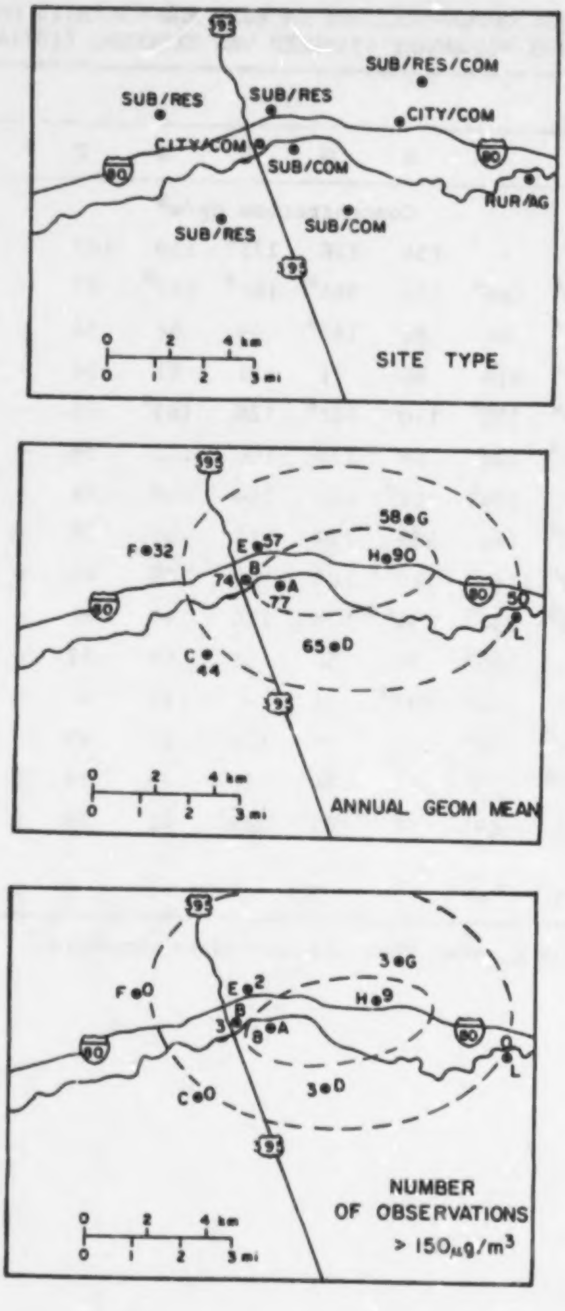

395
SUB/RES/COM
SUB/RES
SUB/RES
CITY/COM
CITY/COM
80
SUB/COM
80
RUR/AG
SUB/RES
SUB/COM
395
0 2 4 km
0 1 2 3 mi
SITE TYPE
395
58 G
F 32
E 57
H 90
B
74
A
77
80
80
50
L
65 D
C
44
395
0 2 4 km
0 1 2 3 mi
ANNUAL GEOM MEAN
395
3 G
F 0
E 2
B
H 9
3
8
A
80
80
0
L
C 0
3 D
395
NUMBER
OF OBSERVATIONS
> 150μg/m³
0 2 4 km
0 1 2 3 mi

Figure 17. Spatial distribution of TSP concentrations and land use in and around Reno.

TABLE 8. TSP CONCENTRATIONS IN RENO AND VICINITY ON DAYS WHEN THE SECONDARY STANDARD WAS EXCEEDED (10/74-9/75)

Date	Site									No. > 150 µg/m³
	H	A	B	G	D	E	C	F	L	
	Concentration µg/m³									
10/02/74	134	-	134	128	173[a]	130	103	-	88	1
10/20/74	174[a]	186[a]	121	366[a]	181[a]	153[a]	87	-	106	5
10/26/74	100	94	82	187[a]	99	86	54	-	64	1
11/07/74	154[a]	113	86	71	121	81	54	-	52	1
11/13/74	197[a]	182[a]	110	161[a]	128	189[a]	65	-	96	4
11/19/74	152[a]	107	84	125	100	111	56	-	48	1
12/19/74	137	204[a]	162[a]	135	100	149	96	-	-	2
01/12/75	170[a]	144	139	120	118	105	78	-	52	1
01/18/75	152[a]	166[a]	140	105	124	108	85	-	55	2
01/24/75	206[a]	234[a]	154[a]	139	124	149	64	-	59	3
01/30/75	95	165[a]	98	60	58	68	52	-	26	1
02/11/75	142	200[a]	202[a]	77	-	124	64	-	39	2
03/01/75	298[a]	156[a]	132	96	114	87	49	-	50	2
04/24/75	161[a]	73	87	74	86	73	36	38	-	1
06/17/75	71	69	66	53	200[a]	41	38	2	82	1
No. > 150 µg/m³	9	8	3	3	3	2	0	0	0	28

[a] Concentrations greater than the secondary standard.

exceeded the standard at only one site. The greatest number of simultaneous exceedances was 5 on October 20, 1974, followed by 4 on November 13, 1974. Thus on the occasions when high concentrations did occur, they were almost always confined to small geographic areas.

On October 20th, wind speeds were light but increased to about 15 mph early in the afternoon and remained near this level for the balance of the day. The maximum wind speed reached during the day was 24 mph. In contrast, on November 13th the winds were very light throughout the day with the fastest mile of wind reported at the airport being 3 mph. Although high wind speed may have contributed to the high concentrations observed on October 20th, this is not the case on November 13th. It is of interest to note that a large high pressure system that had dominated the Great Basin for several days was just beginning to weaken on the 13th. This suggests a regionwide accumulation of the finer particulates, a possibility supported by the fact that five of the Las Vegas sites also exceeded the standard on that day. Using a Chi Square analysis PEDCo designated November 13th as a high regionwide concentration day in both Reno and Las Vegas.

PARTICULATE LEVELS IN AND AROUND TUCSON

Tucson is a moderately large city (1977 population of 301,200)[36] located in a desert valley that runs northwest-southeast between the Santa Catalina and Rincon Mountain ranges to the northeast and east and the Tucson Mountains to the west. The climate is characterized by abundant sunshine and a long hot summer extending from April to October. Precipitation averages about 11 inches per year. Roughly half of the precipitation occurs during summertime showers (July-September); the balance is distributed throughout the year, with a secondary maximum during December and January. Surface winds are generally light and frequently undergo a diurnal change in direction as a result of the daily heating and cooling cycle of the mountain slopes and channeling by the local topography. Early morning winds are usually from the southeast quadrant; during the day the winds become northwesterly. Tucson has no heavy industry and is supported primarily by tourism, agriculture and government services. Copper mining and refining is extensive, but is removed from the immediate metropolitan area.

The air quality data reviewed in this section come from two sources. The first, a report by the University of Arizona (Moyers et al[2]), contains averages of 24-hour concentrations measured at 11 sites from September 1975 to October 1976 under a program sponsored by the Electric Power Research Institute (EPRI). The second is the National Aerometric Data Bank (NADB) which provides 1977 annual geometric means and individual 24-hour observations. The monitoring network used in obtaining the two sets of data is shown in Figure 18 and described in Table 9. The EPRI network comprised the sites numbered from 1 through 11, as designated in the report; the NADB network comprised all sites from 1 through 16 except for the remote site at the Research Ranch (Site 11). Note that the monitor at Sites 10 and 14 are at heights of 47 and 80 feet respectively, while the remaining heights range from 6 to 25 feet.

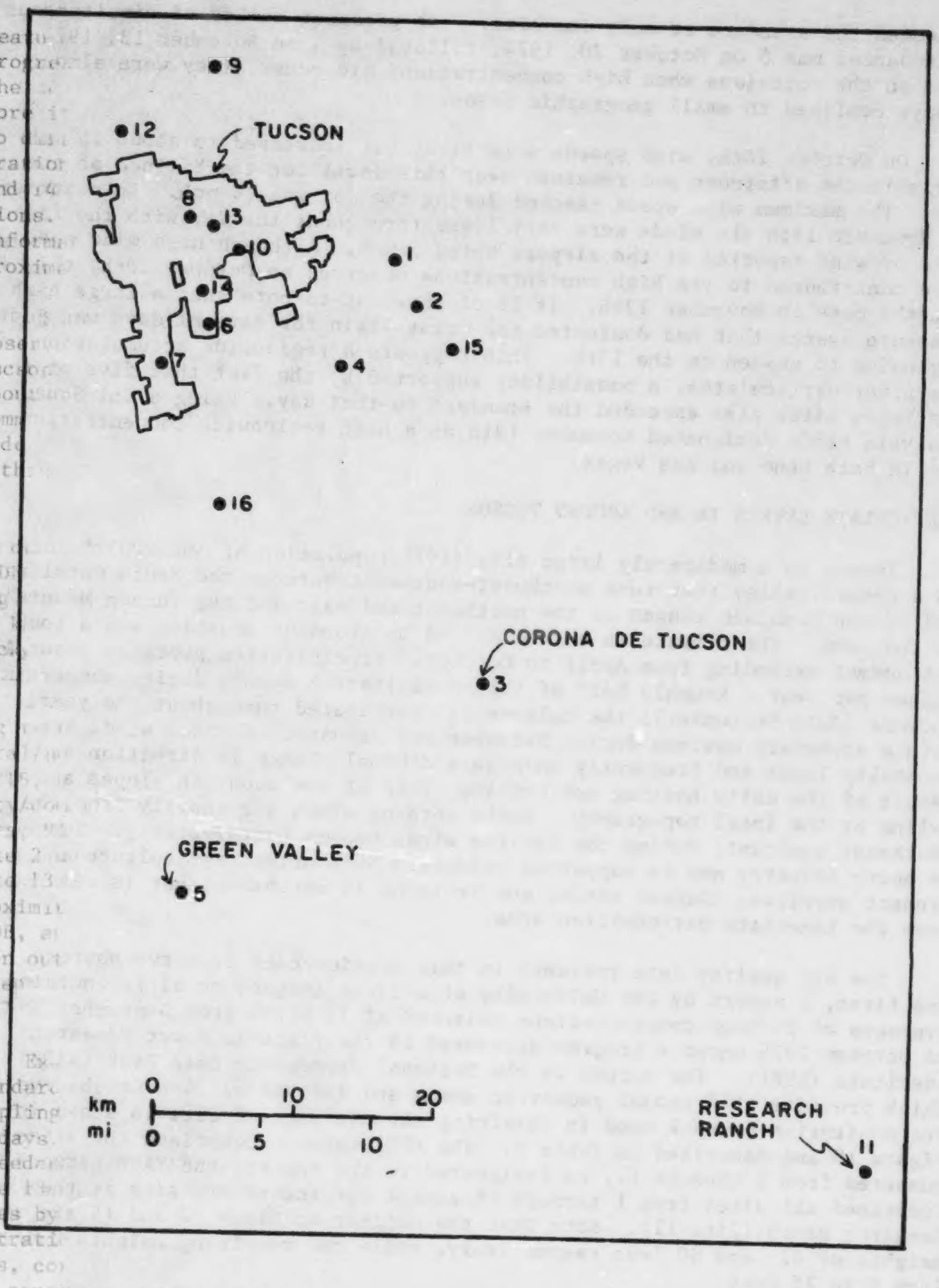

9
12
TUCSON
8
13
10
1
14
2
6
15
7
4
16
CORONA DE TUCSON
3
GREEN VALLEY
5
km 0 10 20
mi 0 5 10
RESEARCH RANCH
11

Figure 18. TSP monitoring network in Tucson and vicinity.

TABLE 9. SITE LOCATION DESCRIPTIONS FOR TUCSON MONITORS

Designator	Site address	Site type	Height of monitor (ft)
1	7920 E. Tanque Verde	Suburban/residential	16
2	7901 E. Scarlett	Suburban/residential	18
3	Route 7 (Corona De Tucson)	Remote	13
4	Davis Mountain Air Force Base	Suburban/industrial	14
5	245 West Esperanza (Green Valley)	Suburban/commercial	13
6	1810 S 6th Ave. (S. Tucson)	Center City/commercial	18
7	1970 W Ajo Rd.	Suburban/residential	18
8	1019 Prince Rd.	Center City/commercial	25
9	Magee Rd. Florence Highway	Rural/near urban	6
10	University of Arizona, 2nd and Palm	Center City/commercial	47
11	Research Ranch	Remote	
12	Orge Gr Rd. and El Camino De Terra (Tucson)	Suburban/residential	6
13	3915 E Ft. Lowell Rd.	Suburban/commercial	15
14	151 W Congress	Center City/commercial	80
15	2400 Harrison Rd.	Suburban/residential	6
16	Nogales Highway and Hughes Access Rd.	Rural/near urban	6

Figure 19 displays the 1977 annual geometric means on the site map. Two features of the spatial distribution are of special interest. The first is a progressive increase in mean concentration as the urban core is approached; the second is the large variation in concentration observed within the urban core itself. A significant part of the latter variation appears to be related to differences in the height of the monitors. In particular, the low concentrations that appear to be nonrepresentative of the urban core at Sites 10 and 14 are quite likely due to the greater measurement heights at those locations. Reports reviewed for this study do not contain sufficient siting information to speculate upon the reasons for other large differences between proximate monitors (Sites 1, 2, and 15, for example).

Some comment should be made, however, on the difference in concentration observed at Sites 3 and 5, located more than 40 kilometers from the center of Tucson. Site 3 is located in a retirement community with a population of about 1,000 and no through traffic. Site 5 is in a somewhat larger retirement community (population of about 5,000) located on an interstate highway with moderate amounts of through traffic. There are also two large copper mines within five miles to the north.

Figure 20 is a plot of annual concentration versus distance from Site 14 in downtown Tucson. The EPRI data are represented by open circles and the NADB data by filled circles. Sites 10 and 14 have been omitted from the figure. If, as suspected, the relatively high concentration at a distance of 52 km is due to the impact of local sources, then the figure suggests that background levels are reached within 40 km of the center of Tucson.

Averaging mean concentrations for similar site types provides the following relationships: background concentration, (Sites 3 and 11), 26 $\mu g/m^3$; rural/near urban, (Sites 9 and 16), 61 $\mu g/m^3$; suburban/residential (Sites 12, 1, 15, and 7), 72 $\mu g/m^3$; suburban/industrial, (Site 4), 76 $\mu g/m^3$; and center city/commercial (Sites 6, 8, and 13), 133 $\mu g/m^3$. In calculating these averages, Sites 10 and 14 were omitted because of their greater monitoring heights, Site 2 was omitted because data were available only from Januray through July, Site 13 was considered to be center city rather than suburban because of its proximity to Sites 8 and 10 both of which were classed as center city in the NADB, and Site 5 was omitted because it was considered to be a special situation outside of the urban influence of Tucson, but with local source impact. Except for the inclusion of Site 11 data, the averages were calculated from 1977 NADB concentrations.

Examination of the 24-hour observations for 1977 shows that the secondary standard of 150 $\mu g/m^3$ was exceeded at one or more of the sites on 39 of the 61 sampling days; Table 10 lists the concentrations at all of the sites on these 39 days. The sites have been arranged in the table so that the number of exceedances per site (and degree of urbanization) decreases from left to right. Site 13, at the left of the table, experienced the greatest number of exceedances by far. There were, in fact, only two days out of the 39 when the concentration at Site 13 was observed to be below the standard; on the two other days, concentration was not reported. Furthermore, on 19 of the days when the concentration exceeded the standard at Site 13, all other reported values throughout the monitoring network were below the standard. Clearly, a local

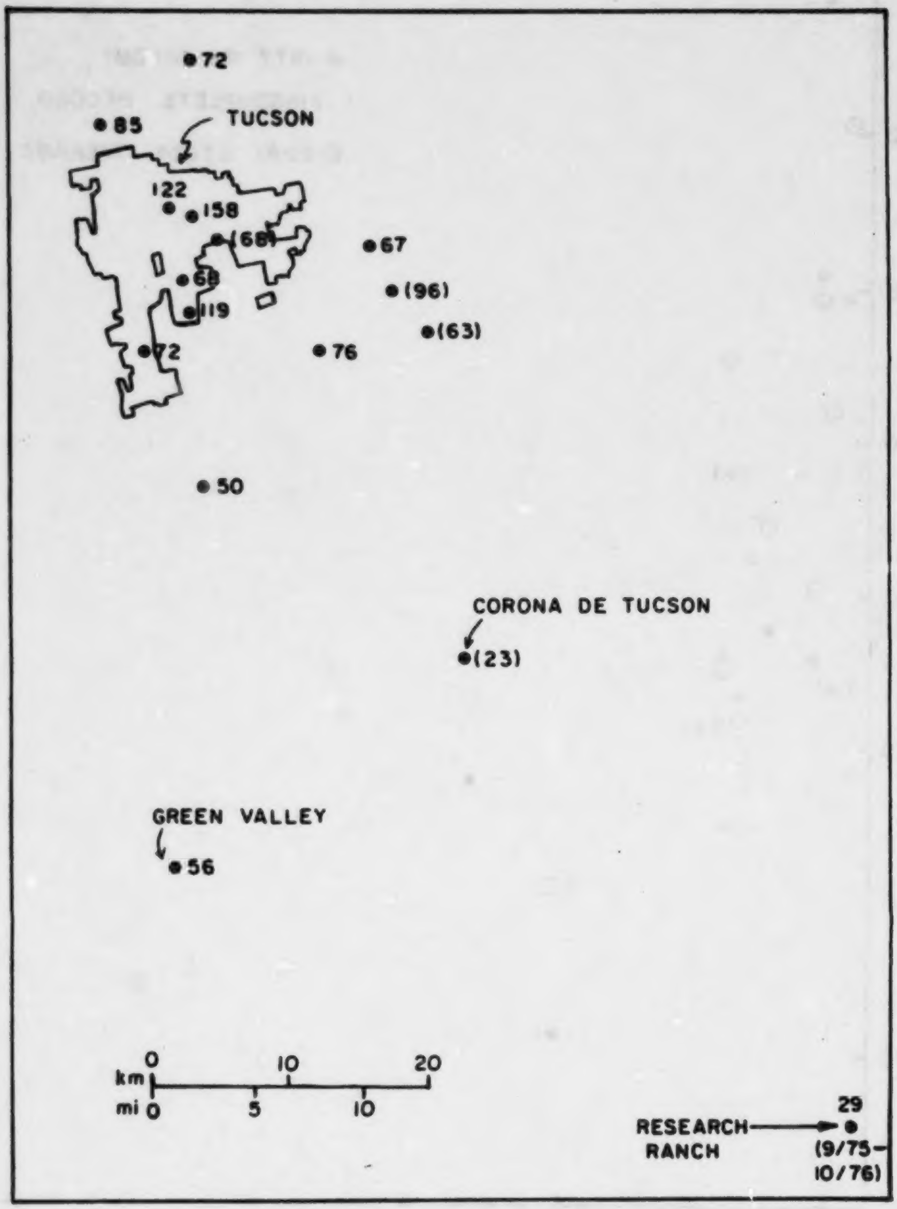

72
85
TUCSON
122
158
(68)
67
68
(96)
119
(63)
72
76
50
CORONA DE TUCSON
(23)
GREEN VALLEY
56
0
10
20
km
mi
0
5
10
29
RESEARCH RANCH
(9/75-10/76)

Figure 19. Annual geometric mean TSP concentrations ($\mu g/m^3$) in and around Tucson in 1977. Values in parentheses are derived from incomplete record.

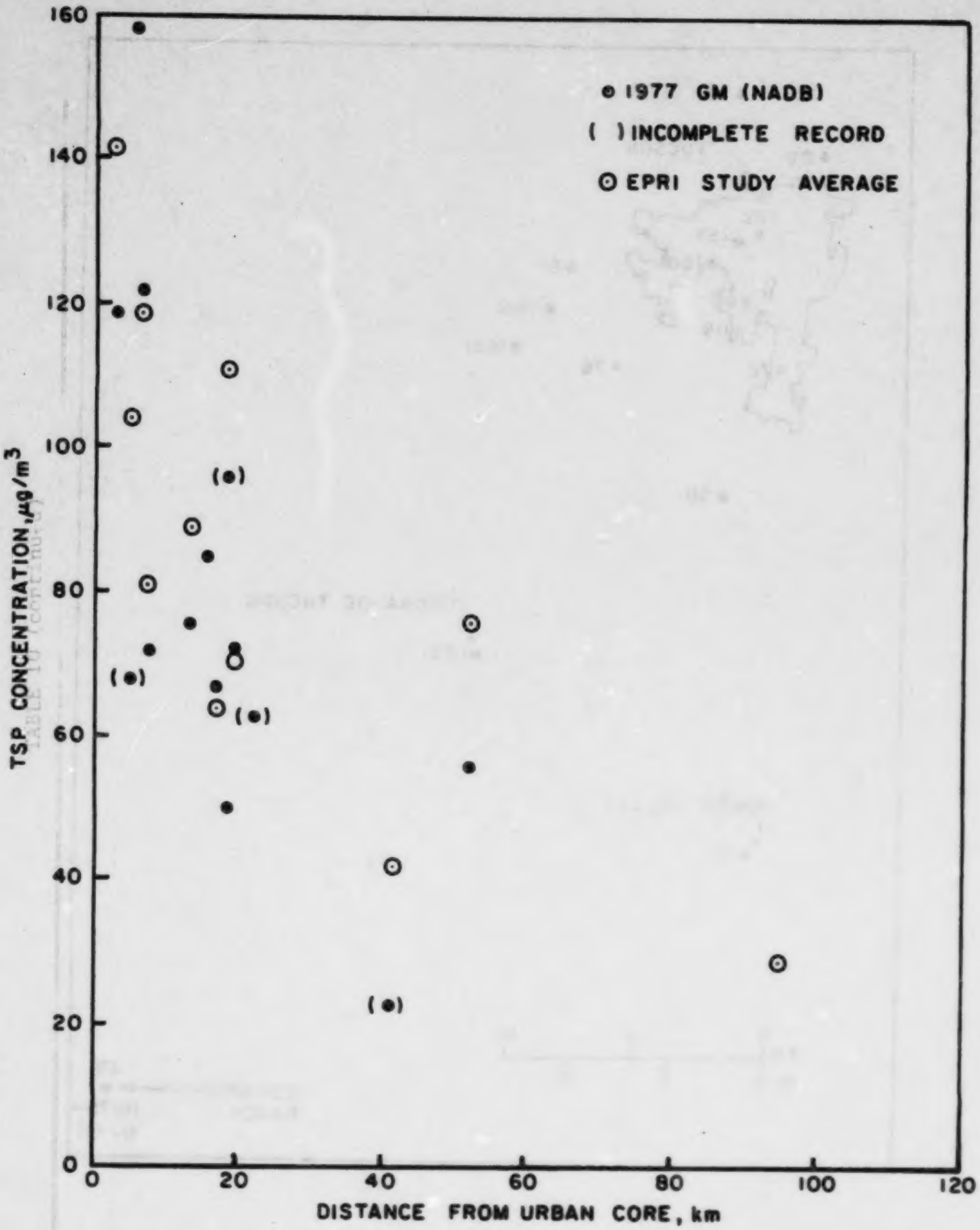


Figure 20. Average TSP concentration versus distance from the urban core. (Site 14, Tucson).

TABLE 10. TSP CONCENTRATIONS IN TUCSON AND VICINITY ON DAYS WHEN THE SECONDARY STANDARD WAS EXCEEDED IN 1977

Date	Site															No. > 150 μg/m³
	13	8	6	9	12	2	7	4	14	1	16	10	15	5	3	
	Concentration (μg/m³)															
01/13/77	182[a]	122	101	39	66	127	47	75	67	65	41	65	-	56	-	1
01/19/77	239[a]	144	103	57	-	135	79	74	69	-	62	83	-	66	-	1
02/06/77	250[a]	143	111	55	-	110	171[a]	71	69	89	52	69	-	62	-	2
02/12/77	283[a]	257[a]	206[a]	82	-	-	122	102	108	93	66	111	-	90	-	3
02/18/77	301[a]	211[a]	168[a]	108	152[a]	154[a]	113	99	109	130	69	124	-	72	-	5
02/24/77	-	204[a]	223[a]	111	215[a]	185[a]	122	182[a]	135	60	95	89	121	73	-	5
03/02/77	225[a]	156[a]	136	-	112	123	104	116	109	101	85	99	110	119	-	2
03/08/77	227[a]	155[a]	141	113	177[a]	89	113	96	114	115	107	113	58	78	-	3
03/14/77	204[a]	146	135	92	103	117	95	111	110	85	80	101	85	92	-	1
03/20/77	179[a]	133	98	99	89	-	119	62	66	70	59	78	73	59	-	1
04/01/77	174[a]	76	66	39	52	90	39	58	38	47	33	52	48	50	23	1
04/07/77	202[a]	129	104	114	89	88	65	69	63	84	52	81	64	56	28	1
04/13/66	189[a]	98	140	89	76	93	85	88	74	90	48	77	64	44	24	1
04/25/77	191[a]	111	80	71	79	92	58	76	64	53	53	86	46	57	30	1
05/07/77	157[a]	93	92	81	87	121	65	49	54	58	48	51	68	43	24	1
05/13/77	-	124	160[a]	191[a]	-	210[a]	64	74	82	87	88	115	102	66	40	3
05/19/77	186[a]	-	124	104	84	98	73	83	75	83	55	71	69	59	35	1
05/25/77	177[a]	108	112	98	72	86	65	57	58	67	43	65	66	58	25	1
05/31/77	170[a]	112	117	109	103	96	105	68	82	72	70	83	86	81	41	1
06/18/77	231[a]	132	132	68	115	100	77	66	72	93	61	82	84	75	43	1
06/24/77	161[a]	126	120	124	96	75	67	74	83	73	59	83	70	12	40	1
06/30/77	169[a]	108	110	105	124	116	77	72	77	85	63	85	74	88	38	1
07/06/77	158[a]	97	91	86	76	-	71	61	63	75	-	80	61	57	-	1
07/12/77	117	123	154[a]	77	129	71	107	147	92	63	-	65	55	47	31	1

(continued)

TABLE 10 (continued)

Date	Site 13	8	6	9	12	2	7	4	14	1	16	10	15	5	3	No. > 150 μg/m³
	Concentration (μg/m³)															
08/05/77	179[a]	108	110	61	88	-	63	74	68	-	63	72	67	64	27	1
08/29/77	161[a]	153[a]	-	110	-	-	73	93	82	-	50	89	64	71	29	2
09/28/77	191[a]	118	84	119	82	-	50	-	62	76	44	72	-	51	26	1
10/04/77	160[a]	100	87	162[a]	67	-	60	-	54	52	39	-	-	41	14	2
10/16/77	102	208[a]	119	81	85	-	-	75	79	67	61	-	61	58	42	1
10/22/77	216[a]	-	131	86	93	-	70	84	75	-	52	-	92	62	28	1
10/28/77	202[a]	198[a]	-	131	132	-	91	80	-	78	64	-	61	75	13	2
11/03/77	191[a]	204[a]	-	184[a]	90	-	84	107	86	100	47	-	-	78	20	3
11/15/77	261[a]	177[a]	407[a]	119	-	-	84	112	96	35	75	-	79	96	32	3
11/21/77	279[a]	175[a]	159[a]	145	111	-	83	114	102	104	58	-	91	-	27	3
11/27/77	183[a]	170[a]	177[a]	56	102	-	147	55	73	-	38	-	64	46	17	3
12/03/77	222[a]	247[a]	305[a]	107	149	-	119	70	17	-	63	-	90	63	20	3
12/09/77	413[a]	331[a]	661[a]	290[a]	192[a]	-	112	149	141	178[a]	81	-	99	120	23	6
12/15/77	322[a]	228[a]	352[a]	158[a]	133	-	121	109	86	130	51	-	107	143	22	4
12/21/77	204[a]	209[a]	624[a]	189[a]	196[a]	-	591[a]	308[a]	223[a]	117	261[a]	-	66	214[a]	84	10
No. > 150 μg/m³	35	16	12	6	5	3	2	2	1	1	1	0	0	1	0	85

[a] Concentrations greater than the secondary standard.

problem exists at this site. Note also that the two sites with the next highest number of exceedances, (16 and 12, respectively) are city center sites No. 8 and No. 6.

Table 11 contains wind speed and direction data for the four days with the greatest number of exceedances. The day with the most widespread problem was December 21, 1977, when 10 of the 13 sites reporting exceeded the standard. The sustained high winds observed throughout the day suggest that this is a classic case of wind-generated fugitive dust (see Section 3, p. 27). Winds were from the southeast and exceeded 20 mph for much of the day; the highest wind speed reported at the airport was 42 mph. Based on afternoon and evening wind speeds, it is also likely that wind-generated dust contributed heavily to the high levels observed on February 24, 1977; of the 61 sampling days, February 24th experienced the second highest average wind speed (13.5 mph). On the other hand, airport wind speeds suggest that wind-generated dust was probably not a major factor on either February 18, 1977, or December 9, 1977. On December 9th, two concentrations in excess of 400 μg/m^3 were observed but the highest wind speed was only 13 mph and the wind speed for the day averaged only 6.5 mph.

TABLE 11. WIND CONDITIONS ON DAYS WITH THE GREATEST NUMBER OF VIOLATIONS IN TUCSON

					Fastest mile		
No. > 150 μg/m^3	Date	Hour (MST)	Wind direction (deg)	Wind speed (knots)	Speed (mph)	Direction	Average speed (mph)
5	02/18/77	02	140	7	14	SE	9.4
		05	140	10			
		08	140	9			
		11	160	3			
		14	320	5			
		17	360	6			
		20	250	5			
		23	160	6			
5	02/24/77	02	160	6	36	SW	13.5
		05	140	6			
		08	00	0			
		11	320	8			
		14	250	20			
		17	220	25			
		20	240	15			
		23	300	14			
6	12/09/77	02	140	8	13	S	6.5
		05	140	9			
		08	140	8			
		11	150	5			
		14	00	0			
		17	40	4			
		20	160	5			
		23	140	6			
10	12/21/77	02	130	25	42	SE	21.6
		05	120	16			
		08	120	23			
		11	120	23			
		14	110	18			
		17	120	16			
		20	120	16			
		23	120	13			

Notes: 1 knot = 1.15 mph - 0.515 m/sec
Wind speed tabulated under "fastest mile" is a measure of the maximum wind speed during the 24-hr period. It is calculated from the length of time required for one mile of wind to pass the anemometer. The direction tabulated under "fastest mile" is the direction measured during this period.

PARTICULATE LEVELS IN AND AROUND PHOENIX

Phoenix is located on the broad, nearly flat plain of the Salt River Valley. The Salt River runs from east to west through the valley, but is almost always dry. Mountains rise in nearly every direction, the closest being the South Mountains to the south and the larger Phoenix Mountain Range to the north and northeast. The metropolitan area of Phoenix, with a population of over one million, is the largest of the four urban areas studied. In addition to the city of Phoenix, it includes the cities of Scottsdale, Tempe and Mesa to the east, and Glendale to the northwest. In 1977 these cities had the following populations: Phoenix — 684,516; Scottsdale — 81,458; Tempe — 98,146; Mesa — 110,079; and Glendale — 73,730.[36] The unincorporated area of Sun City lies farther to the northwest, roughly 10 miles beyond Glendale. The centralized urban area is surrounded by pockets of urban development, particularly in the extensive agricultural areas to the west and southeast. These include Avondale, Goodyear, Litchfield Park, Tolleson and Cashion to the west, and Chandler and Mesa to the southeast. Manufacturing and tourism also contribute substantially to the economy of the area.

The climate is desert-like with low annual rainfall (about 7 inches), high summertime daytime temperatures, and low humidity. Rainfall is centered on two seasons of the year. The first is from November to March when occasional storms from the Pacific reach the area, and the second is during July and August when Arizona is subjected to widespread thunderstorm activity. May and June are the driest months and frequently experience no significant precipitation. The valley floor is rather free of wind. During the spring months southwest and west winds associated with the passage of low pressure troughs predominate. During the thunderstorms season local gusty winds often occur, usually from an easterly direction. Because of the topography and predominance of weak pressure gradients, mountain-valley wind circulations are common. Typically, downslope east-to-west flow is established about 8 p.m. and lasts until early morning; the flow reverses about noon and lasts until after sunset.

The principal basis for the following discussion is Volume I of the series of four support documents prepared for EPA by TRW Environmental Engineering Division entitled "An Implementation Plan for Suspended Particulate Matter in the Phoenix Area."[1] The air quality data analyzed in this document came from 17 monitoring sites operating throughout all or part of 1973 through 1975. Figure 21 locates these sites with respect to the center of Phoenix, and Table 12 provides site type and additional location data.

The duration of the sampling periods at the various sites was inconsistent. However, TRW used the available distributions to calculate the annual geometric means and maximum 24-hour concentrations that would have been expected under a 60-sample per year measurement program. This was usually done by fitting a log-normal distribution to the data; in three cases the actual distribution appeared to seriously over predict concentrations at the high end, and an adjustment to the log-normal fit was made. Comparison of expected with actual concentrations showed good agreement in the case of annual means; the expected maximal 24-hour values were generally higher than measured maximal values, however. This would be expected for those cases where fewer than 60

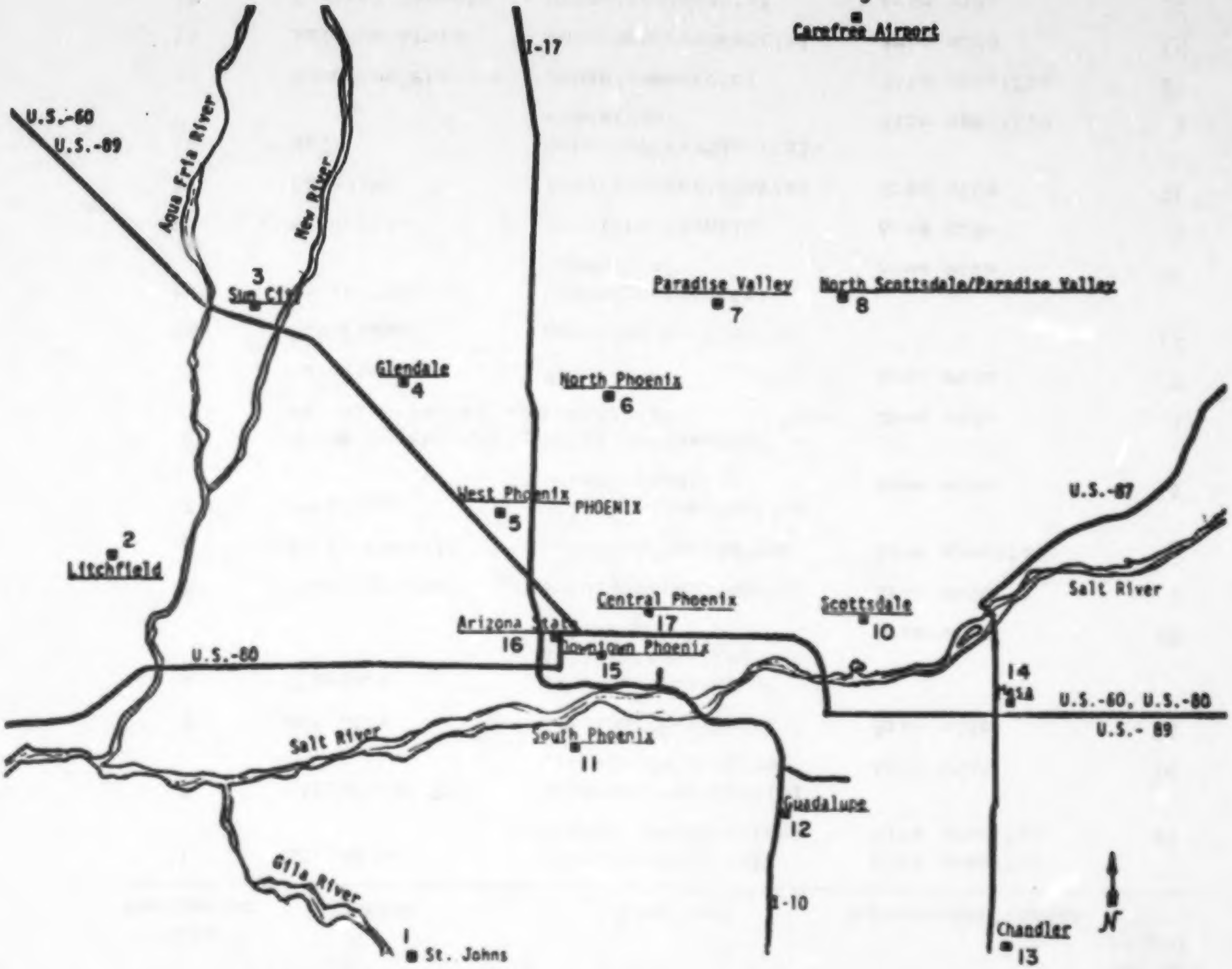

9
Carefree Airport
I-17
U.S.-60
U.S.-89
Agua Fria River
New River
3
Sun City
Paradise Valley
7
North Scottsdale/Paradise Valley
8
Glendale
4
North Phoenix
6
West Phoenix
5
PHOENIX
U.S.-87
2
Litchfield
Salt River
Central Phoenix
17
Scottsdale
10
Arizona State
16
Downtown Phoenix
15
U.S.-80
14
Mesa
U.S.-60, U.S.-80
U.S.-89
Salt River
South Phoenix
11
Guadalupe
12
Gila River
I-10
N
Chandler
13
1
St. Johns

Figure 21. Hi-vol monitoring sites within the Phoenix area (TRW).[1]

TABLE 12. SITE LOCATION DESCRIPTIONS FOR PHOENIX MONITORS

Site designator	Site	Site type	Representativeness	Monitor height (ft)
1	St. Johns	Rural/residential (Indian Reservation)	Site specific Site specific	15
2	Litchfield Park	Suburban/residential (growth in progress)	Area wide	10
3	Sun City	Suburban/residential	Area wide	25
4	Glendale	Suburban-rural/ Residential-Agricultural	Area wide	20
5	West Phoenix	Suburban/residential	Area wide	5
6	North Phoenix	Suburban/residential	Site specific	5
7	Paradise	Suburban/residential (development)	Area wide	5
8	North Scottsdale/ Paradise Valley	Rural/residential-commercial	Area wide	5
9	Carefree	Remote	Area wide	5
10	Scottsdale	Suburban/residential	-	15
11	South Phoenix	Urban/residential-commercial	Area wide	36
12	Guadalupe	Rural/residential	Area wide	5
13	Chandler	Suburban/residential	Area wide	21
14	Mesa	Suburban/residential-commercial	Site specific	5
15	Downtown Phoenix	Urban/commercial	Site specific	23
16	Arizona State	Suburban/residential	Area wide	15
17	Central Phoenix	Urban/residential	Area wide	22

observations were made per year. In part, the differences may be due to a failure of the log-normal distribution to properly fit actual TSP data at the high concentration end of the distribution.

The expected annual geometric means and expected maximal 24-hour TSP concentrations are shown on site maps in Figures 22 and 23, respectively. TRW concluded that the lack of a consistent spatial pattern in both figures was due to the influence of local fugitive dust sources and hence related to the site environment. For example, sites in rural/residential areas are frequently surrounded by numerous vacant fields and unpaved roads. Also, construction activities, frequent in such areas, disturb the soil surface, making it susceptible to suspension by wind. Other rural/residential sites were surrounded by improved property lacking obvious fugitive dust sources.

Table 13 presents average concentrations for the site categories developed by TRW. Data for the individual sites within each category can be found in Table 5-1 of the TRW report. Because of the influence of fugitive dust, it is very likely that monitor height is a complicating factor. Note in Table 12 that height ranges from 5 to 36 feet above the ground. No attempt was made to factor in monitor height in preparing Table 13, however. Although the highest annual average concentration occurs in the central city/residential-commercial environment, the highest 24-hour concentrations occur outside the city in rural/residential environments surrounded by fugitive dust sources.

Closer examination of the data reveal that meteorological conditions and the ambient particulate distributions associated with high TSP concentrations fall into two patterns. One is primarily a wintertime phenomenon characterized by low wind speeds and low mixing heights. Under these conditions, high concentration centers around the city monitoring sites and often at Paradise Valley. Concentrations also increase at other stations throughout the region, although to a lesser degree. The other pattern occurs most frequently from March to August during periods with strong wind gusts from the southeast or west and above average wind speeds during the day. Under these circumstances, concentrations are highest at the rural and suburban residential sites. These responses of the particulate field to meteorological conditions support the following two-part hypothesis put forth by TRW:

1. "Human activity, which is most densely focused in the city area, is responsible for suspension of substantial fugitive emissions. These emissions are of higher density than those released at the rural sites and this is reflected by the higher concentrations produced durthe stable atmospheric conditions of winter."

2. "Because vast expanses of agricultural land, unpaved roads, and unimproved (but disturbed) soil surfaces surround the rural sites, suspension of dust by soil wind erosion is very likely a dominant factor affecting high particulate levels during gusty winds in the rural areas. Soil erosion by wind is of less consequence in the more developed areas."

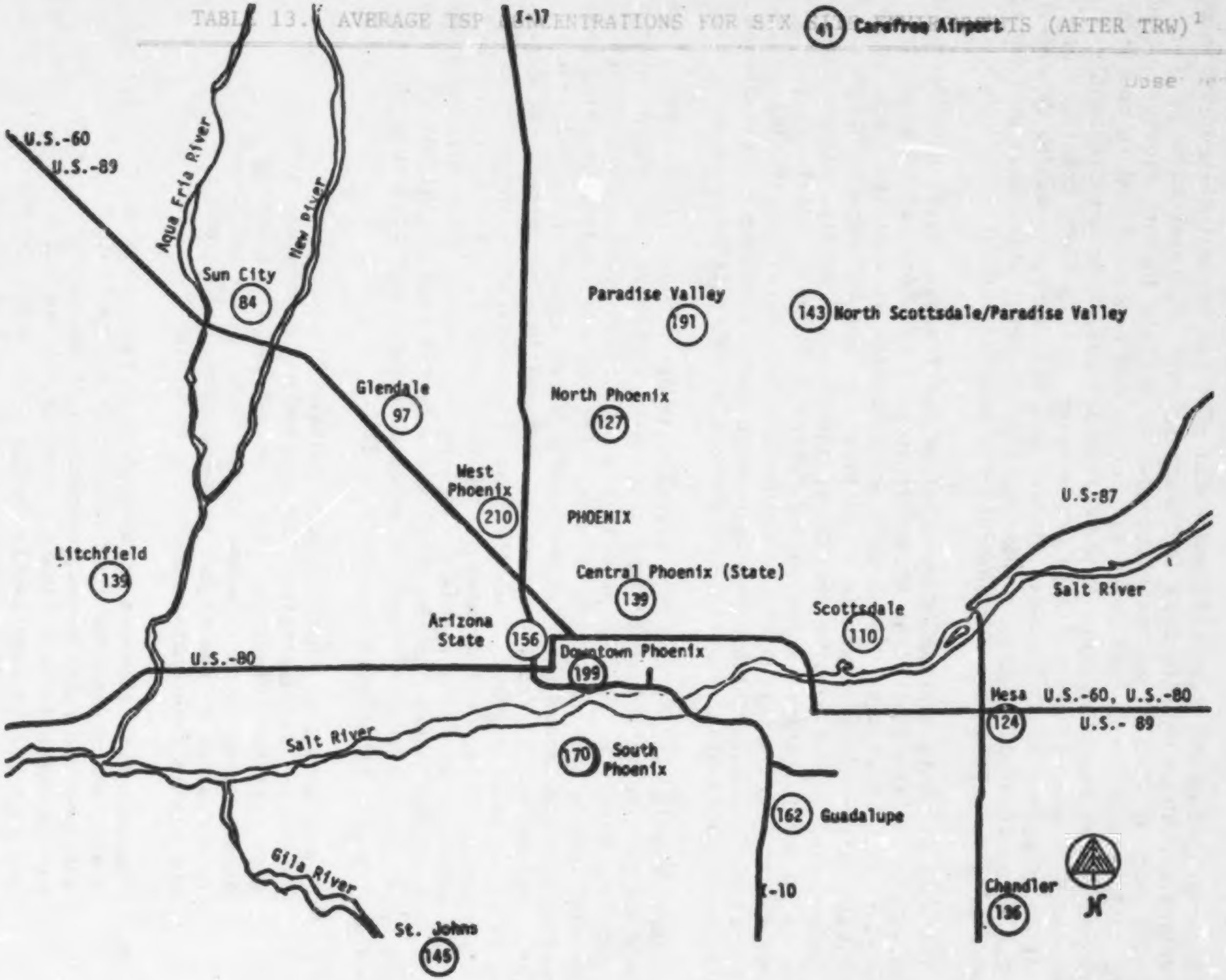

41 Carefree Airport
I-17
U.S.-60
U.S.-89
Aqua Fria River
New River
Sun City
84
Paradise Valley
191
143 North Scottsdale/Paradise Valley
Glendale
97
North Phoenix
127
West Phoenix
210
PHOENIX
U.S.-87
Litchfield
139
Central Phoenix (State)
139
Salt River
Scottsdale
110
Arizona State
156
Downtown Phoenix
199
U.S.-80
Mesa
124
U.S.-60, U.S.-80
U.S.-89
Salt River
170
South Phoenix
162
Guadalupe
Gila River
I-10
Chandler
136
N
St. Johns
145

Figure 22. Expected annual geometric means in µg/m³ (TRW).[1]

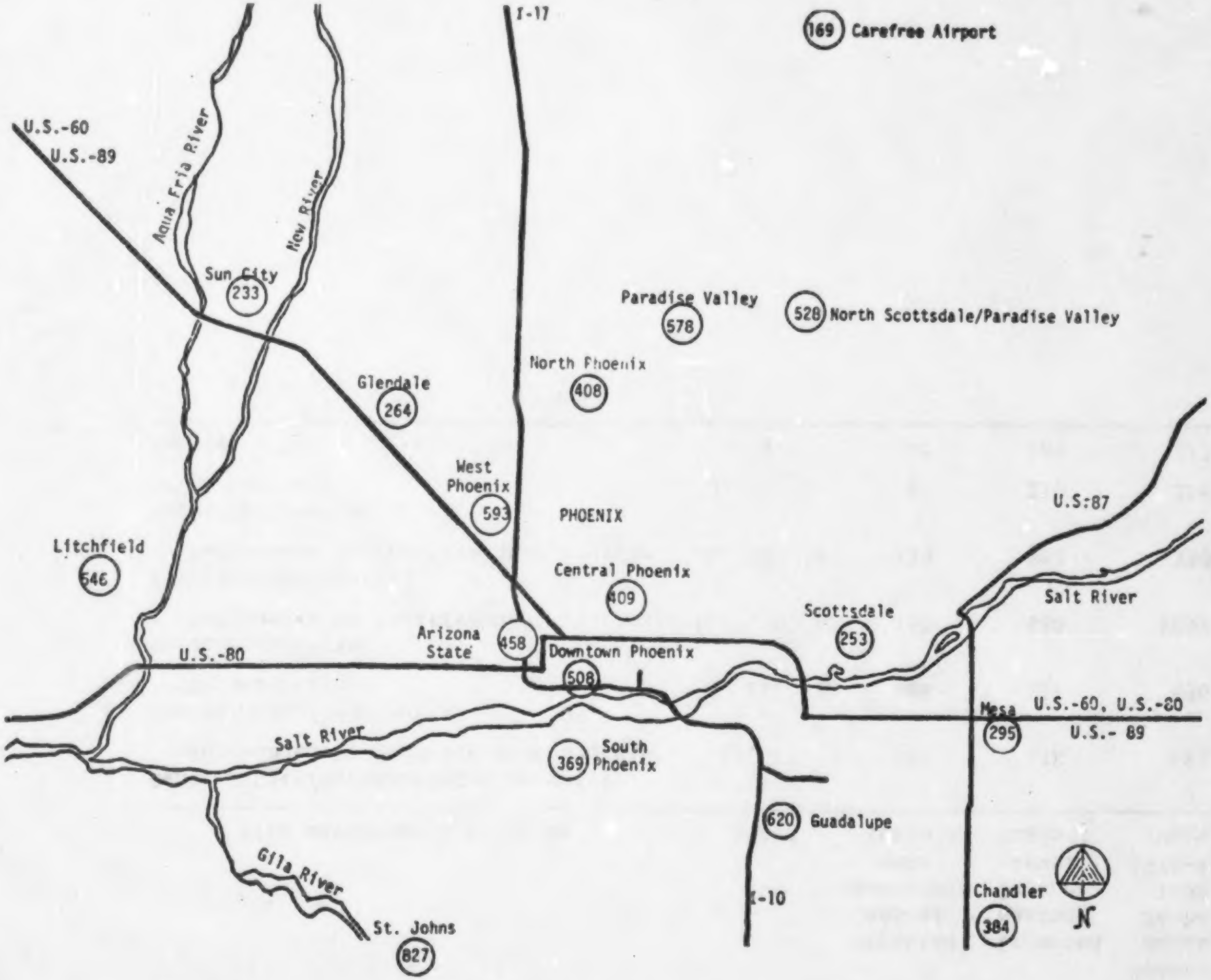

169 Carefree Airport
I-17
U.S.-60
U.S.-89
Agua Fria River
New River
Sun City
233
Paradise Valley
578
528 North Scottsdale/Paradise Valley
North Phoenix
408
Glendale
264
West Phoenix
593
PHOENIX
Litchfield
546
Central Phoenix
409
U.S:87
Salt River
Scottsdale
253
Arizona State
458
Downtown Phoenix
508
U.S.-80
Mesa
295
U.S.-60, U.S.-80
U.S.- 89
Salt River
South Phoenix
369
620 Guadalupe
Gila River
I-10
Chandler
384
St. Johns
827
N

Figure 23. Expected maximal 24-hour concentrations in µg/m^3 (TRW).[1]

TABLE 13. AVERAGE TSP CONCENTRATIONS FOR SIX SITE ENVIRONMENTS (AFTER TRW)[1]

Site environment category	Sites	Expected annual geometric mean (μg/m^3)	Expected maximal 24-hour level (μg/m^3)	Observed maximal 24-hour level, 1973-1975 (μg/m^3)
Central City/Residential-Commercial (Surrounded by fugitive dust sources)	11, 15	184	438	481
Central City/Residential (No sources)	5, 16, 17	168	487	436
Rural/Residential (Surrounded by fugitive dust sources)	1, 7, 8, 12	160	638	1099
Suburban/Residential (Surrounded by fugitive dust sources)	6, 13, 14	129	362	380
Rural/Residential (No sources)	3, 4, 10	97	250	256
Remote	9	41	169	277

The relationships between wind speed and concentration leading to the two particulate patterns are illustrated qualitatively in Figure 24. Human-activity-related emissions result in high concentrations when dilution is minimal as a result of light winds; in contrast, the contribution from wind erosion is insignificant during light winds, but can be of overiding importance in areas with disturbed soil surfaces when wind speeds are high.

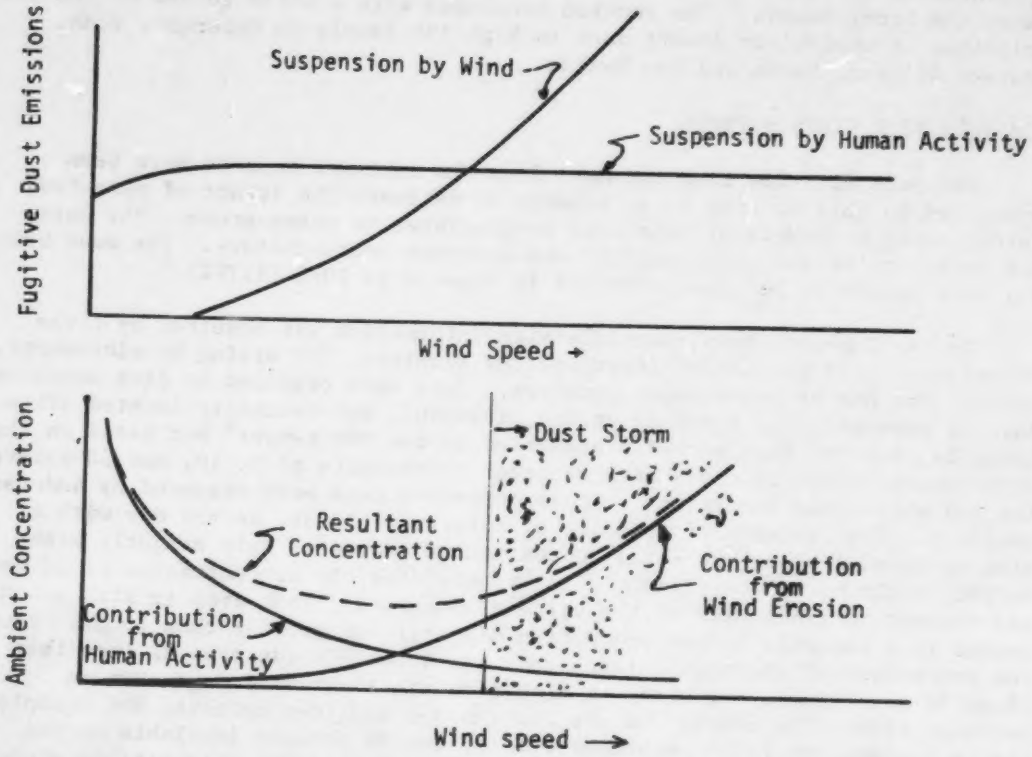


Figure 24. Effect of wind speed on ambient suspended particulate levels (TRW).[1]

SECTION 5

URBAN PARTICULATES: CHARACTERISTICS AND SOURCES

This final section discusses the characteristics and sources of urban particulates in the Southwest, focusing on the contribution of wind-blown desert dust. It begins with a summary of particle size measurements that emphasizes the inhalable size fraction. Next, the discussion turns to the sources of particulates in several urban areas including Phoenix and Tucson, Arizona, and Las Vegas and Reno, Nevada. The section concludes with a brief review of the contribution of wind-blown desert dust to high TSP levels in Colorado, Utah, Western Arizona, Texas and New Mexico.

PARTICLE SIZE DISTRIBUTIONS

Particle size distribution data from the reviewed reports have been assembled in this section in an attempt to estimate the impact of dust from desert areas on levels of inhalable particulates in urban areas. The data are very limited and unfortunately are somewhat contradictory. The most useful data appear to be those obtained in Phoenix in 1975 (IITRI).[8]

In the Phoenix study, particle size information was acquired by three techniques: (1) the use of fractionating samplers, (2) sizing by microscopy, and (3) the use of dichotomous samplers. Data were obtained on five sampling days at several heights and at upwind, downwind, and centrally located sites. Table 14, derived from material presented in the TRW report[3] but based on the IITRI study, presents cross-city averages for heights of 3, 10, and 30 meters for two wind speed conditions. These concentrations were measured by Andersen samplers. Two features of data are of interest. First, on the day with a wind speed of 4 m/sec the total concentration decreases only slightly with height, while on the very light wind or calm days the concentration at 30 meters has dropped to about half of the value at 3 meters. This drop is also accompanied by a decrease in the proportion of particles greater than 15 µm. Second, the percentage of the particulates that are inhalable (defined as less than 15 µm in aerodynamic diameter) is higher on the light wind days than on November 18th. The average values for the 3-m and 10-m heights, for example, are 44 percent inhalable on November 18th, and 59 percent inhalable on the other three days. These results agree qualitatively with expectations since mixing is enhanced by increasing wind speed and the principal sources of the larger particles subject to gravitational setting are at ground level.

Particle size analysis of hi-vol filters from three heights were also carried out by IITRI by microscopy. Table 15, taken directly from Volume 3 of the TRW report,[3] shows the results for one windy day (average wind speed of 4.4 m/sec) and one calm day. Over this smaller height interval, no

TABLE 14. HEIGHT VARIATION OF PARTICULATE CONCENTRATIONS FROM ANDERSEN SAMPLER DATA (TRW,[3] IITRI[8])

Height above ground (m)	November 18, wind = 4 m/sec		November 17, 21, 25, wind = 1 m/sec	
	Total concentration (µg/m^3)	Percent <15 µm	Total concentration (µg/m^3)	Percent <15 µm
3	112	46	149	52
10	107	42	90	66
30	105	38	79	66

Note: Data from five sites were used to compile these averages.

TABLE 15. PARTICLE SIZE DISTRIBUTION FOR SUSPENDED PARTICULATES MEASURED IN PHOENIX, SEPTEMBER 27 AND NOVEMBER 14, 1975 (TRW[3])

	Percent of particles (by weight) in size range			
	2 µm	2-8 µm	8-20 µm	>20 µm
September 27 (windy)				
Monitors at 20 feet	.07	2.8	32.2	65.0
Monitors at 15 feet	.06	2.2	33.0	64.6
Monitors at 5 feet	.05	2.0	28.3	69.7
November 14 (calm)				
Monitors at 20 feet	.14	2.8	32.4	64.7
Monitors at 15 feet	.14	2.5	29.5	67.9
Monitors at 5 feet	.13	2.7	34.9	62.6

significant differences were found in the particle size distributions with either height or wind speed. On both occasions, approximately 65 percent of the particulates were greater than 20 μm in diameter. If, as a rough approximation, half of the particulates in the 8-20 μm size range were less than 15 μm, only 18 percent of the particulates found on these filters would have been classed as inhalable. Note that optical micorscopy generally does not account for particles smaller than about 1-2 μm; consequently, this technique may severly underestimate the percent of particulates that are inhalable.

The third summary prepared from the IITRI data, Table 16, compares results obtained from dichotomous samplers with results obtained by the microscopic analysis of hi-vol filters. The data for each day listed in Table 16 are average values from all available measurements; however, only 11 pairs of dichotomous sampler — hi-vol observations from the same location (site and height) are contained in the data set. Table 17 lists the concentrations from the collocated samplers. The average concentrations measured by the two devices on these 11 occasions were almost identical: 232 μg/m^3 by dichotomous sampler and 228 μg/m^3 by hi-vol. There were some very large discrepancies, however, but no consistent bias. Linear correlation between the two sets of data, shown in Table 17, results in a correlation coefficient of + 0.66, which is significant at the 5 percent level.

TABLE 16. PARTICLE SIZE INFORMATION FROM PHOENIX SAMPLING PROGRAM (IITRI[8])

	Dichotomous sampler			High-volume sampler*			
Date	Number of samples	<3.5 μm	>3.5 μm	Number of samples	<5 μm	5-15 μm	>15 μm
			(Mass Percent)				
11/17/75	5	35	65	5	11	42	47
11/18/75	6	28	72	4	5	35	60
11/21/75	4	32	68	6	17	41	42
11/23-24/75	5	45	55	6	15	52	33
11/25/75	5	32	68	6	13	45	42
Average	-	34	66	-	12	43	45

* Estimated by optical microscopy.

TABLE 17. TSP CONCENTRATIONS MEASURED BY HI-VOLS AND DICHOTOMOUS SAMPLERS

	Concentration, μg/m³			Concentration, μg/m³	
Date	Dichotomous sampler	Hi-vol	Date	Dichotomous sampler	Hi-vol
11/17/75	253	221	11/21/75	250	315
11/17/75	210	206	11/23-24/75	122	142
11/18/75	460	441	11/23-24/75	106	116
11/18/75	136	287	11/25/75	170	258
11/18/75	499	257	11/25/75	197	157
11/21/75	149	108	Average	232	228

Although a direct comparison between the results obtained by the two techniques, is impossible, it is instructive to note that the percent found to be less than 5 μm by microscopy is consistently much less than the percent found to be less than 3.5 μm by use of the dichotomous sampler. Also note that microscopy indicates that, on average, 55 percent (12 plus 43) of the particulates are inhalable.

A small amount of information is available from the PEDCo study of Las Vegas and Reno. In this report results are presented for three sites in or near each city where size distributions were determined by microscopy. When averaged within each city, 30 percent by weight of the particulates were found to be less than 15 μm. In this analysis, the particles collected on sections of the glass-fiber, hi-vol filters were resuspended in distilled water with the use of an ultrasonic bath and refiltered onto a membrane filter prior to sizing. In IITRI's analysis, particles were counted as collected on the filter through the use of immersion oil.

The data summarized above are too limited and the estimates cover too broad a range to be of much help in defining inhalable particulate levels within the urban areas. Further, no information was found on the proportion of incoming particulates that is less than 15 μm. Thus, it appears that a comprehensive measurement program will be required before the impact of dust from desert areas on the levels of inhalable particulates within the cities can be reliably ascertained.

PARTICULATE SOURCES

Phoenix

Several studies of Phoenix reviewed for this report examined the contribution of wind-blown dust from the desert to high levels of TSP in urban locations. Two of these studies concluded that high particulate levels should not be attributed to wind-blown dust from the undisturbed desert region surrounding

Phoenix and its suburbs. Instead they implicated anthropogenic sources as the prime contributors to the TSP problem. Several of the other studies present evidence that supports this conclusion.

The first two studies relied on different techniques to reach very similar conclusions. IITRI's Aerosol Sampling and Analysis[8] used several analytical techniques to characterize Phoenix particulates including mass flux determinations, particle size and morphological analysis, and elemental analysis. The second report, Dust Transport in Maricopa County,[7] relied exclusively on the emissions inventory/modeling approach.

The purpose of the IITRI study was to determine whether high TSP levels in Phoenix are due to human activities within the Phoenix area or to long-range transport from the surrounding desert. To answer this question, authors of the study designed a sampling program to collect and measure aerosols both upwind and downwind of Phoenix. This sampling program took into account the typical diurnal pattern of wind direction in Phoenix: day wind from the west, night wind from the east. Microscopic and elemental analysis was used to determine the physical and chemical characteristics of the particulate samples collected.

The study found that the sizes and morphologies of the majority of mineral particles found in the Phoenix samples were not typical of wind-eroded materials. Instead of being frosted, indicating tumbling and collision with finer particles, particle surfaces tended to be scratched with fine particles embedded suggesting mechanical wear. In addition, TSP concentrations were not significantly higher in a day when the wind-speed increased to 5 m/sec compared to other sampling days when wind speeds averaged 1 m/sec. The report concluded that "wind is not the primary source for suspension of particles" and "long-range transport of aerosols by winds from the surrounding deserts is only a minor source for suspended particulates."

The report went on to state that "vehicular traffic, especially on unpaved roads is the primary generator of suspended particles." According to the authors, the appearance of smooth-surfaced, worm-shaped, rubber tire particles, fine carbonaceous particles, and sharp, angular mineral fragments indicate vehicle travel over paved roadways while torn, rough-surfaced rubber tire particles and fine carbonaceous particles, together with rounded clay coated minerals indicated vehicle travel over unpaved roads and shoulders.

The report cautions that agricultural activity could also produce the round, clay-coated mineral fragments attributed to vehicle travel over unpaved roads. The authors felt, however, that the relative absence of plant or fertilizer materials in the samples suggested that agricultural activity generated less suspended particulate matter than vehicular traffic.

The second report, Dust Transport in Maricopa County, Arizona relies on a behavioral model of suspended particulate dynamics to analyze the contribution of dust, including wind-blown desert dust, to high urban particulate levels in and around Phoenix. Three major categories of dust emissions were considered: (1) traffic dust from unpaved roadways and off-roadway vehicle emissions, (2) "diurnal dust" - windblown desert dust and agricultural and construction emissions and (3) "constant dust" consisting of tailing piles, cattle feed lots, and vacant soil emissions. The analysis is limited to the late fall, a period characterized by fairly light winds, when - according to the study - high ambient particulate concentrations are usually observed. The report concluded that: "observed high particulate concentrations in Maricopa County urban areas during late fall and winter periods of atmospheric stability are associated with local fugitive dust sources. Because of light drainage winds prevalent during these periods, advective transport of dust from countryside to the urban areas is not an important contribution to urban supermicrometric particulate concentrations."

Several other studies also examined TSP nonattainment in the Phoenix metropolitan area. TRW Environmental Engineering Division produced a study for EPA that focused on the development of control strategies for total suspended particulates in the Phoenix area. As part of this study, TRW developed an emission inventory[37] that included estimates of emissions from wind-blown desert dust, then used this inventory to model air quality in the Phoenix area.

The TRW study relied on both the Climatological Dispersion Model (CDM) and the Linear Rollback model (LR) to simulate the relationship between emissions and ambient air quality in the Phoenix area. The study assumed that particulates smaller than 20 μm aerodynamic diameter could be adequately modeled with the CDM model, and those greater than 20 μm could be adequately treated in the context of the LR modeling concept. Particle size distributions for emissions were estimated from a number of different sources.

The model predicts that nearly all the TSP level (excluding background) at 12 of the 13 sites monitoring in 1975 was caused by emissions from unpaved roads, entrained street dust, construction activities, or wind erosion. Wind-erosion includes emissions from agricultural fields, unpaved roads, undisturbed desert, tailings piles, and vacant lots. Table 18 indicates that undisturbed desert and disturbed soil are by far the largest sources of these emissions - roughly equal in magnitude. At the Sun City site however off-road vehicles were responsible for most of the TSP levels. Table 19 indicates the relative importance of these four types of sources at each of the 13 sites; in all but a few cases, the contribution of wind-erosion is modest relative to the contribution from unpaved roads and entrained street dust. "Monitors which were most dramatically affected by wind-erosion emissions tended to be located in the rural areas under development, such as the Paradise Valley and North Scottsdale/Paradise Valley sites. (Figure 21 indicates the location of the 13 monitoring sites while Table 12 provides a brief description of the site environments.) Unfortunately, the impacts of the various classes of wind-erosion emissions on TSP levels were not disaggregated in the report.

Figures 25 through 28 display 1975 emissions from the four major sources. Although these figures provide a vivid picture of the spatial distribution of emissions, the reader is cautioned not to use them to compare emissions from different types of sources since all the figures use slightly different scales to measure emission magnitudes. These figures show that emissions from all four sources, even wind erosion, are much greater in the more urbanized portion of the study area. In Figure 28, wind erosion emissions include those from agricultural fields, unpaved roads, undisturbed desert, tailings piles, and disturbed soil. (The monitors roughly define the urbanized portion of the study area; Figure 21 shows the location of each monitor.)

TABLE 18. 1975 TOTAL PARTICULATE EMISSION INVENTORY FOR PHOENIX STUDY AREA (TONS/DAY) (AFTER TRW[3])

	1975				
Source category	1st quarter	2nd quarter	3rd quarter	4th quarter	Annual average
Stationary Sources	22	22	22	22	22
Area Sources	1.4	1.4	1.4	1.4	1.4
Mobile Sources	11	11	11	11	11
Aircraft	.4	.4	.4	.4	.4
Agricultural Tilling	22	30	1	17	20
Venicles on Unpaved Roads	1281	1365	1365	1086	1281
Aggregate Piles	.10	.10	.10	.10	.10
Cattle Feed Lots	6	6	6	6	6
Off-Road Vehicles	71	71	71	71	71
Construction	100	100	100	100	100
Paved Streets	248	248	248	248	248
Wind Blown Agriculture	4.1	4.0	3.8	4.0	4.0
Wind Blown Unpaved Roads	1.4	2.1	2.7	3.8	2.5
Wind Blown Undisturbed Desert	160	244	321	450	294
Wind Blown Disturbed Soil	161	248	323	456	297
Tailing Piles	1.4	1.4	1.4	1.4	1.4
Total	2091	2354	2478	2478	2360

TABLE 19. IMPACT OF MAJOR SOURCES ON TSP LEVELS (AFTER TRW[3])

Monitor site	Contribution of suspended particulates from four major sources ($\mu g/m^3$) TSP in 1975	Unpaved roads	Entrained dust	Construction activities	Wind erosion	Percentage of TSP level contributed from four major sources & background
Central Phoenix	112	25	31	4	19	96.3
South Phoenix	144	75	20	2	15	98.2
Arizona State	169	35	59	7	33	96.4
Glendale	101	30	17	7	15	97.2
North Phoenix	121	26	28	7	28	97.8
North Scottsdale/Paradise Valley	149	24	8	14	71	98.3
Scottsdale	115	27	33	6	16	96.5
Mesa	117	32	35	8	10	97.7
Downtown	200	42	70	8	40	94.1
St. Johns	145	93	2	0	18	98.3
Sun City	88	15	12	3	2	55.2
Paradise Valley	184	42	14	17	78	98.1
Chandler	119	64	10	7	5	96.6

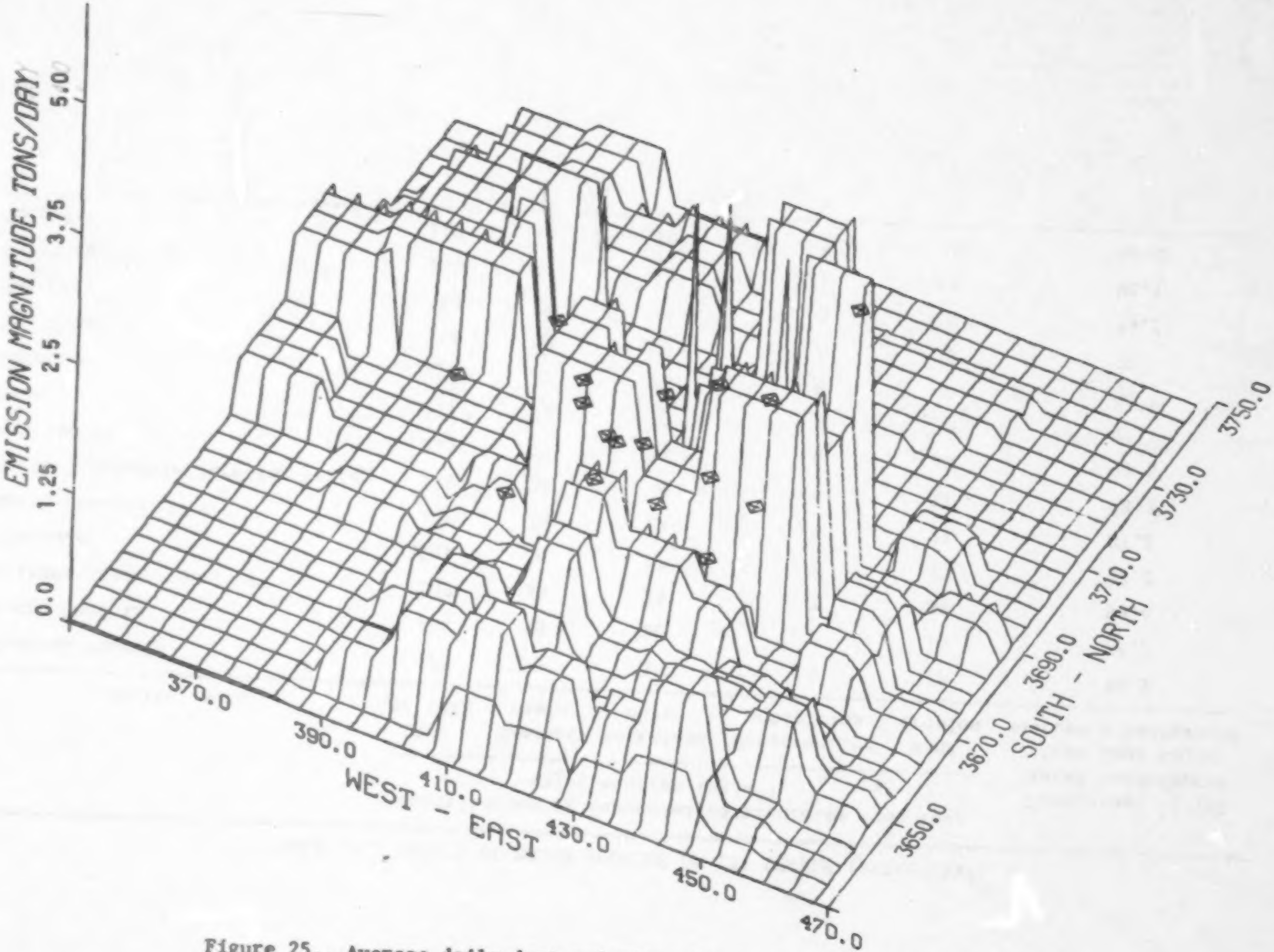


Figure 25. Average daily dust emissions from unpaved roads, 1975. (TRW[37])

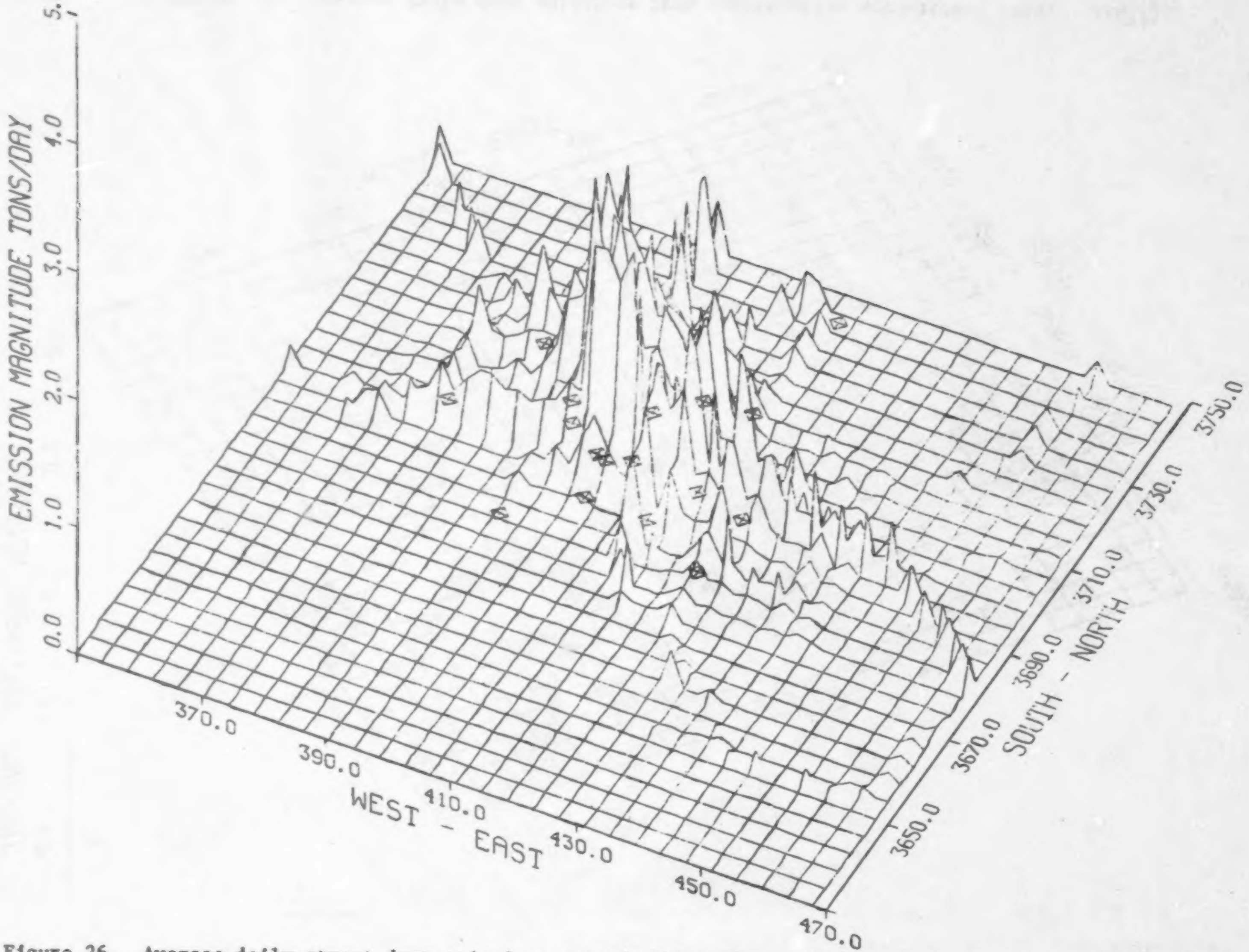


Figure 26. Average daily street dust emissions entrained by motor vehicles on paved streets, 1975. (TRW[37])

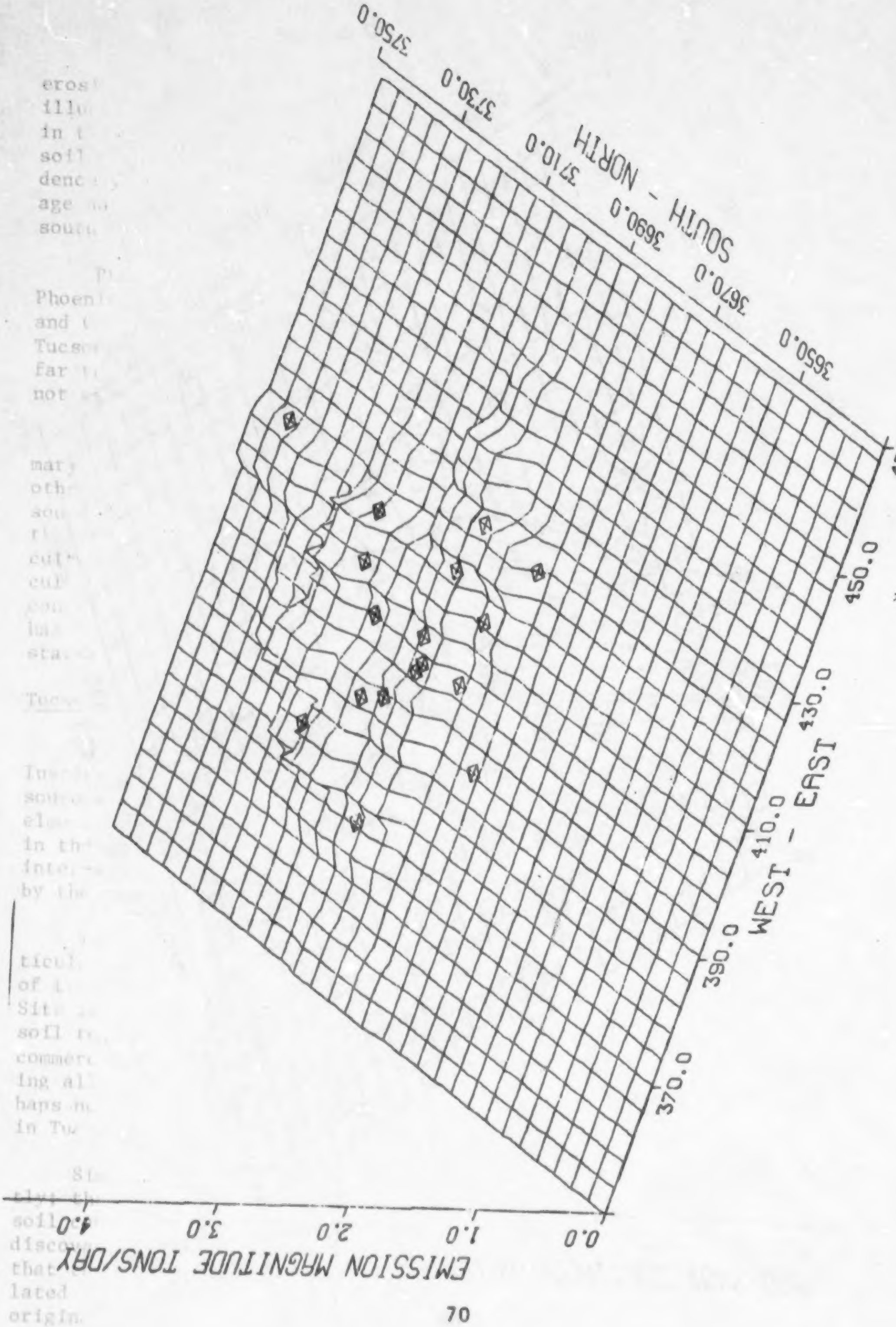


Figure 27. Average daily dust emissions from construction activities, 1975. (TRW[37])

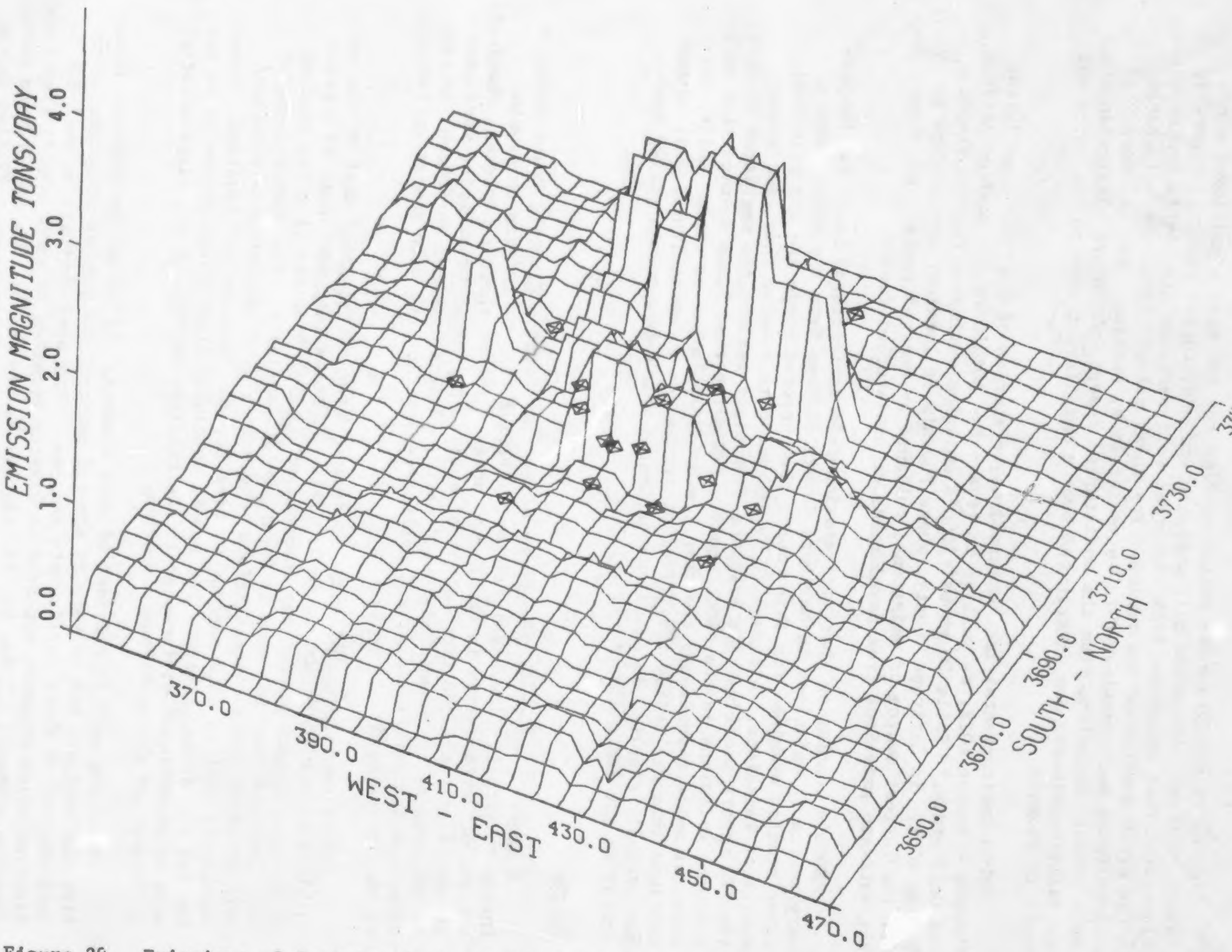


Figure 28. Emissions of fugitive dust arising from wind erosion, average daily emissions, 1975. (TRW[37])

Figures 29 and 30 depict emissions from the two most significant wind-erosion sources: disturbed soil surfaces and undisturbed desert. Figure 29 illustrates that emissions from disturbed soil surfaces are highly concentrated in the urban portion of the region. For these calculations, the vulnerable soil surfaces were considered to be vacant lots, parking lots, and dirt residence yards. Emissions from the undisturbed desert, which are similar in average daily magnitude, are distributed over a much larger area to the north and south of Phoenix.

PEDCo Environmental Inc. examined major sources of fugitive dust in the Phoenix - Tucson AQCR, as well as in five other AQCR's in New Mexico, Arizona, and California.[4] Table 20 shows PEDCo's emission estimates for the Phoenix-Tucson AQCR. In Maricopa County, where Phoenix is located, agriculture is by far the largest source of emissions, followed by unpaved roads. The report does not estimate emissions from paved roads or undisturbed desert.

PEDCo's conclusion that wind-erosion from agricultural lands is the primary source of emissions in Maricopa County differs from the conclusions of other studies examined for this report that unpaved roads are the principal source of emissions. Although it is difficult to resolve this discrepancy, the TRW report provides some evidence that might explain the magnitude of agricultural emissions in the PEDCo study. TRW notes that PEDCo assumed that agricultural soils experienced the same low moisture levels as native soils; they conclude that neglecting the effect of irrigation on agricultural soil losses has probably resulted in emissions estimates which were substantially overstated in the PEDCo inventory.

Tucson

A study done by the University of Arizona for the Electric Power Research Institute (EPRI),[2] discussed earlier, utilizes many techniques to examine sources of particulates in the Tucson area. Some of these techniques, chemical/elemental analysis and examination of spatial patterns for example, were used in the studies of Phoenix discussed above. Others, such as enrichment factors, inter-species correlations, and pattern recognition are used almost exclusively by the Tucson study.

The evidence compiled in the study indicates that a great deal of the particulate matter in Tucson is soil. Table 21 shows that more than 50 percent of the particulate matter was composed of soil at 9 of the 11 sites studied. Site locations may be found in Figure 18 of Section 4. The contribution of soil to particulate concentrations ranges from 82.7 percent at a suburban/commercial site to 48.2 percent at Site 11, the "background" location. Examining all the sites, however, the report concluded that there appears to be perhaps no significant differences in the relative amounts of soil-like material in Tucson and the background location.

Since the soil is composed of many elements, it cannot be measured directly; the analysts had to rely on several indirect techniques to determine the soil content of their particulate samples. They used correlation analysis to discover which elements appeared to cluster together in each sample; they found that the elements Al, Fe, Si, Ti, Li, Rb, K, Ca, Mg, Na, Mn, and Sr were correlated with each other at both urban and background locations. (Tables in the original report list the inter-species correlation coefficients, r, for the

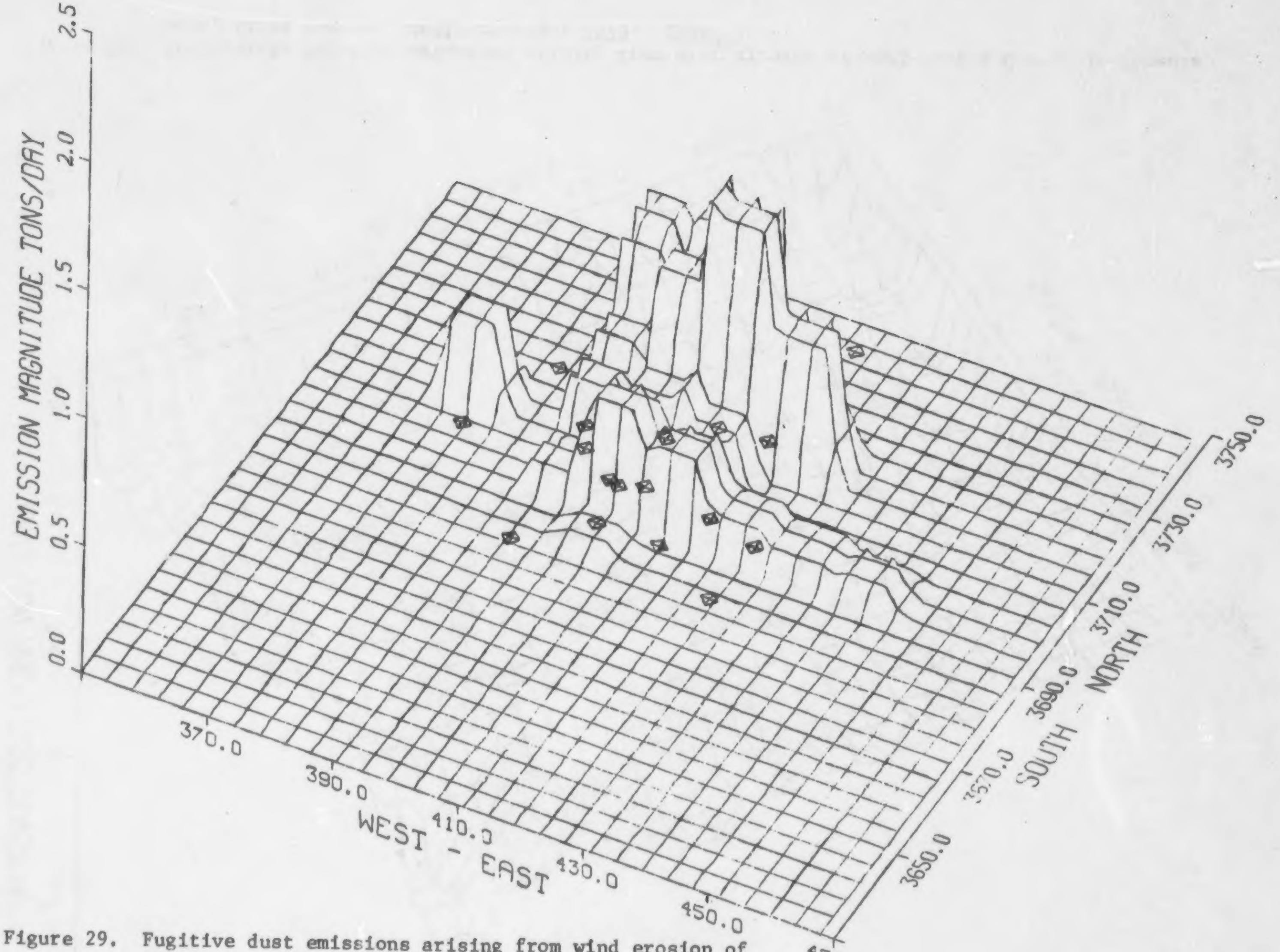


Figure 29. Fugitive dust emissions arising from wind erosion of disturbed soil surfaces, first quarter, daily average, 1975. (TRW[37])

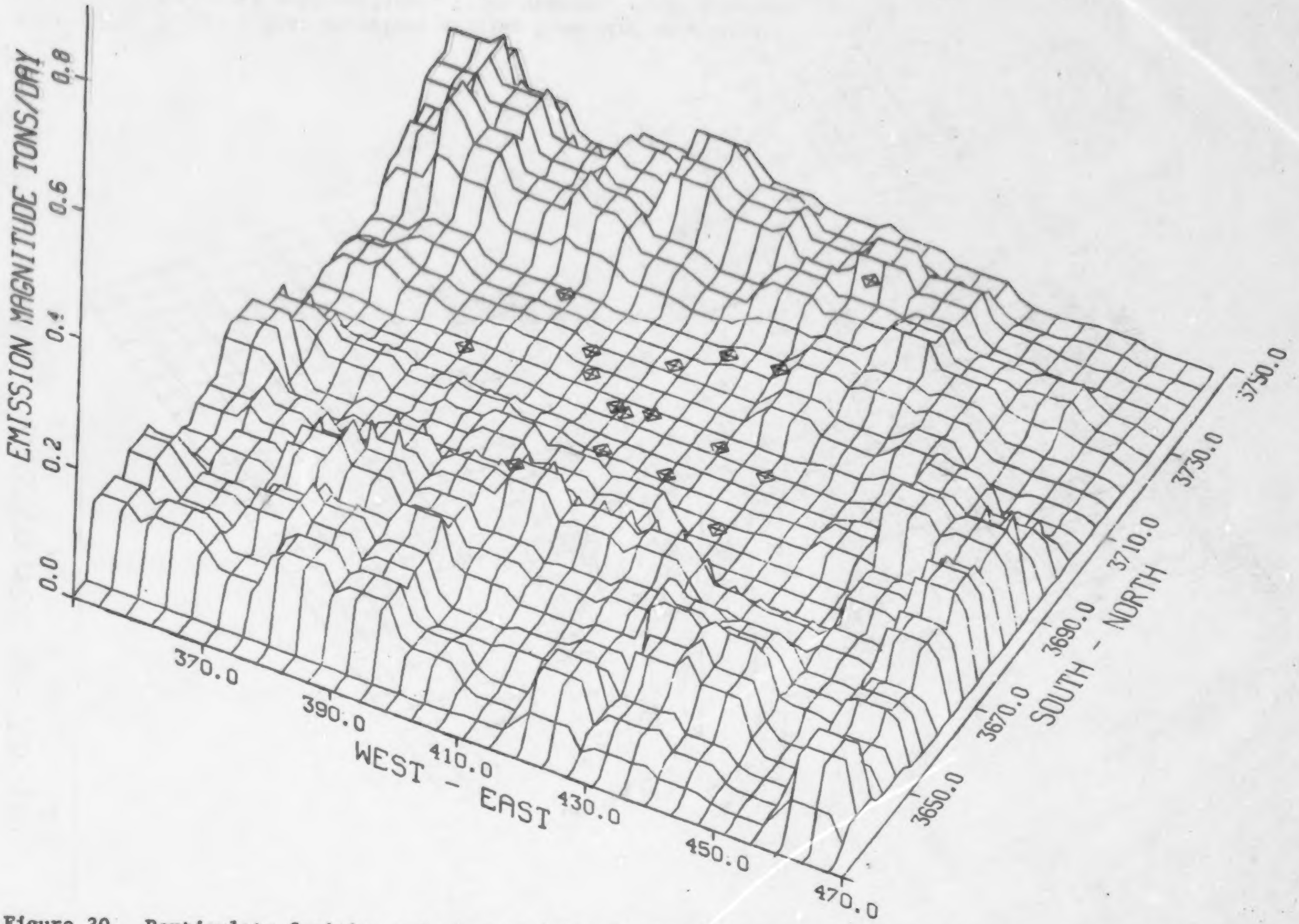


Figure 30. Particulate fugitive emissions arising from wind erosion of undisturbed desert in Phoenix area, first quarter, daily average, 1975. (TRW[37])

TABLE 20. PHOENIX-TUCSON AQCR SUMMARY SHEET, ESTIMATED ANNUAL EMISSIONS FROM FUGITIVE DUST SOURCES (PEDCo[4])

	Unpaved roads		Agriculture		Construction		Tailings piles		Aggregated storage		Cattle feedlots		County emission
County	Vehicle mi/day	Emission tons/yr	Acres	Emission tons/yr	Acres per/yr	Emission tons/yr	Acres	Emission tons/yr	10^3 tons	Emission tons/yr	10^3 head	Emission tons/yr	Total, tons/yr
Gila	13,266	9,200	1,300	50	-	-	1,785	5,430	30	90	-	-	14,770
Maricopa	121,758	82,200	408,500	175,000	3,775	62,440	-	-	552	1,590	235	250	321,470
Pima	45,530	34,910	50,700	8,900	1,440	24,160	2,680	9,430	212	540	13	20	77,960
Pinal	58,936	39,750	238,000	126,500	-	-	1,100	7,100	120	340	230	1,010	174,700
Santa Cruz	9,258	6,250	1,400	50	-	-	-	-	75	220	-	-	6,520
AQCR Activity Total	249,104		699,900		5,215		5,565		989		451		
AQCR Emissions Total		172,310		310,500		86,590		21,960		2,780		1,280	595,420

TABLE 21. SOUTHERN ARIZONA ATMOSPHERIC PARTICULATE MATTER, PERCENT COMPOSITION OF MAJOR COMPONENTS AT EACH LOCATION (EPRI[2])

Location	Soil	$SO_4^= - NH_4^+$	NO_3^-	Pb	Zn - Cu - Cd
1	81.8	4.1	2.2	0.74	0.38
2	52.8	2.7	1.7	0.38	0.15
3	61.7	5.9	2.6	0.10	0.30
4	60.9	4.4	1.8	0.48	0.26
5	82.7	4.2	1.6	0.32	0.33
6	65.2	2.9	1.5	0.61	0.26
7	57.9	4.1	2.0	0.58	0.30
8	49.6	3.5	1.8	0.45	0.22
9	54.2	4.1	1.8	0.28	0.18
10	61.4	3.5	1.4	0.51	0.55
11	48.2	16.4	2.9	0.08	0.47

background location as well as a "typical" urban site." Figures 31 and 32 use cluster analysis, a form of pattern recognition, to display the information conveyed by the correlation coefficients more vividly. The height of the lines connecting elements is proportional to 1-r; thus short vertical lines designate element pairs that are highly correlated, long lines, pairs that are more weakly correlated.

The authors observe that the clustering of these elements suggests a common source (or type of source) for these species and that a likely source for many of these elements would be soil material. To test this hypothesis they examined the enrichment factors of each element. Enrichment factors, E, are defined as:

$$E = \frac{\dfrac{\text{Air Concentration of Element}}{\text{Air Concentration of Reference Element}}}{\dfrac{\text{Crustal Concentration of Element}}{\text{Crustal Concentration of Reference Element}}}$$

An enrichment factor of one indicates that the relative concentration of a given element is the same in both air and soil, supporting the hypothesis that soil is the primary source. An enrichment factor significantly greater than one provides tentative evidence that another source besides soil is contributing the element to the atmosphere. In this study the authors use Al, the second most abundant crustal element, as the reference element.

As Figure 33 shows, enrichment factors for Fe, Si, Ti, Li, Rb, K, Ca, Mg, Na, Mn, and Sr are all close to one lending credibility to the hypothesis that soil is the source of these elements. Unfortunately, this technique does not

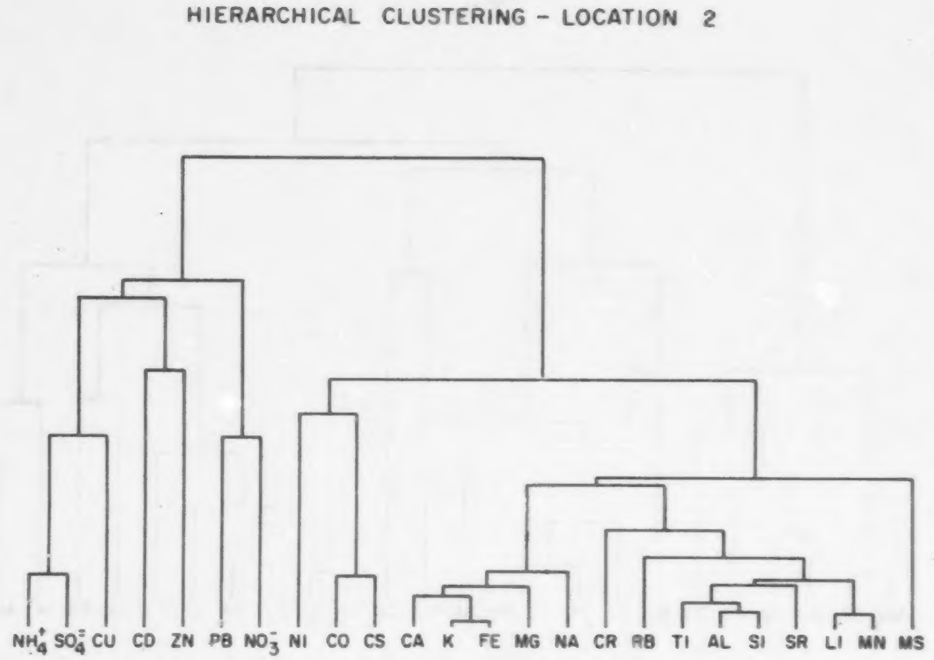


Figure 31. Dendogram of feature clustering for desert urban particulate matter, (EPRI[2]).

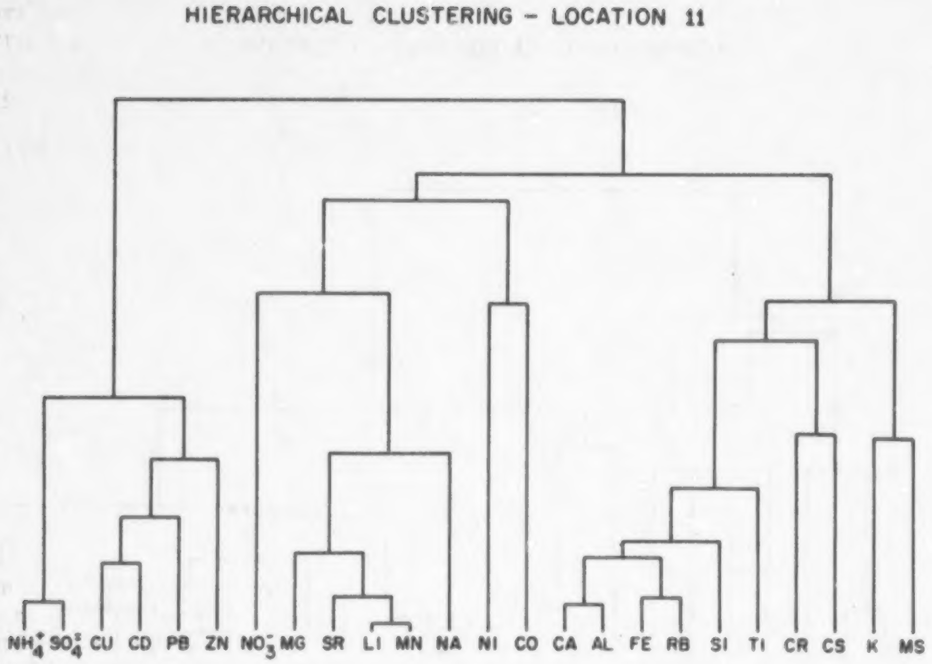


Figure 32. Dendogram of feature clustering for desert background particulate matter, (EPRI[2]).

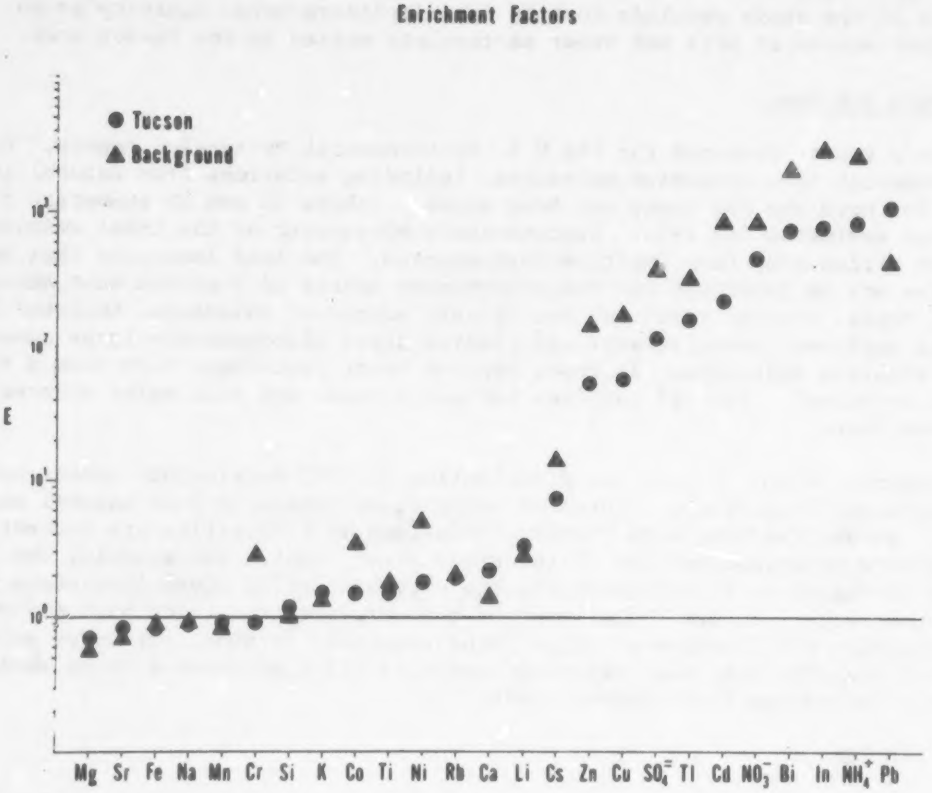


Figure 33. Enrichment factors for species in desert background and urban particulate matter, (EPRI[2]).

distinguish between wind-blown desert soil and soil material suspended as the result of human activities such as travel on unpaved roads.

Urban-background concentration ratios shed some light on the possible sources of soil-related particulate matter. As Table 22 shows, urban-background ratios exceed one for all the soil-related elements at all urban and suburban sites. These ratios typically are higher for the sites within Tucson, lower for sites 3 and 5 which lie between Tucson and Research Ranch, the background site. Although this evidence does not reveal specific urban sources, the authors of the study conclude that it does implicate urban activity as an important source of soil and other particulate matter in the Tucson area.

Las Vegas and Reno

In a report prepared for the U.S. Environmental Protection Agency,[5] PEDCo Environmental Inc. estimated emissions, including emissions from natural surfaces for both the Las Vegas and Reno areas. Tables 23 and 24 summarize their emission estimates for 1975. Approximately 80 percent of the total emissions in both cities come from fugitive dust sources. The data indicates that natural surfaces are an important but not predominant source of fugitive dust emissions. In Las Vegas, unpaved roads are the largest source of emissions, followed by natural surfaces; paved streets and cleared areas also generate large amounts of particulate emissions. In Reno, unpaved roads contribute more than a third of all emissions. Natural surfaces and paved roads are also major sources of fugitive dust.

Figures 34 and 35 show the distribution of 1975 particulate emissions in Las Vegas and Reno; these figures do not include emissions from natural surfaces. As was the case with Phoenix, emissions in both cities are concentrated in the more urbanized portion of the study area. (Note, for example, the magnitude of emissions at points within the city boundaries where interstate highways intersect). In Las Vegas, many of the outlying grids with high emission densities are the location of large point sources. In Reno, the three grids north of the city with high emission densities all experience a large contribution to emissions from unpaved roads.

OTHER STUDIES

The conclusion that emerges from the studies of Phoenix, Tucson, Las Vegas, and Reno is that fugitive dust from urban activities, rather than wind-blown desert dust, appears to be responsible for the high particulate concentrations observed in those cities. Evidence from studies of other areas in the southwest provide some support for this conclusion, although this evidence is not as complete or detailed as that available for the four cities already discussed.

One study[38] compiled emission inventories for the two counties that form Arizona's western border: Mojave and Yuma. Table 25 summarizes the inventories for both counties. Although they do not contain estimates of emissions from undisturbed desert areas, these inventories do indicate the magnitude of other fugitive dust sources in the region. Fugitive dust sources account for approximately 98 percent of all emissions in both counties. In Mohave County, the principal sources of fugitive dust are unpaved roads and vehicle travel on

TABLE 22. URBAN/BACKGROUND CONCENTRATION RATIOS (EPRI[2])

	Site									
Element	1	2	3	4	5	6	7	8	9	10
Pb	10.7	12.1	1.4	10.4	5.5	27.0	10.5	18.0	10.3	15.7
Ca	5.8	6.2	1.7	5.1	3.4	11.7	5.4	6.2	2.1	6.0
K	4.9	5.8	1.5	4.6	3.1	5.9	2.8	4.4	4.0	3.5
Sr	4.7	5.4	1.9	4.6	4.3	13.8	4.3	5.7	2.8	6.0
Mg	4.4	5.3	1.7	4.5	3.3	8.9	3.8	5.2	2.2	4.5
Li	3.9	5.2	1.9	3.7	3.2	5.9	3.5	4.0	2.8	3.7
Rb	3.7	4.4	1.7	3.8	3.8	5.0	2.6	3.8	3.1	3.5
Si	3.7	4.3	1.3	3.3	3.3	4.9	2.6	3.6	2.8	3.5
Al	3.5	4.3	1.3	3.4	3.3	5.3	2.8	3.5	2.8	3.5
Mn	3.5	4.3	1.4	3.3	3.0	4.9	3.0	3.5	2.4	2.9
Na	3.9	4.3	1.8	3.7	3.7	5.5	2.8	4.5	3.5	3.2
Fe	3.4	4.1	1.4	3.5	3.0	5.0	2.6	3.7	2.4	3.0
Mass	2.2	3.7	1.2	3.1	2.3	4.2	2.6	3.7	2.6	3.2
Ti	2.9	3.1	1.2	2.7	3.2	3.9	2.2	2.7	2.2	2.5
Cs	2.2	3.0	1.1	2.1	2.0	2.7	1.6	2.3	1.7	1.9
In	3.8	2.9	2.7	4.1	3.0	5.1	3.8	4.7	2.3	3.5
Tl	3.3	2.8	2.9	3.0	3.0	6.0	3.7	4.2	2.5	3.2
Co	2.8	2.8	2.2	2.8	2.8	4.4	2.2	3.1	2.9	2.4
NO_3^-	2.0	2.5	1.5	2.5	1.5	2.7	2.1	2.3	1.8	2.0
Ni	2.0	1.9	1.2	2.8	1.1	2.8	1.4	2.3	1.6	2.7
NH_4^+	1.3	1.6	1.0	1.6	1.0	1.5	1.4	1.8	1.3	1.2
Zn	1.7	1.6	1.3	1.8	1.3	2.2	1.6	1.5	1.2	1.6
$SO_4^=$	1.3	1.5	1.3	1.6	1.1	1.6	1.5	1.8	1.5	1.2
Cd	1.3	1.5	0.7	3.9	0.9	2.4	0.8	2.4	1.3	4.4
Cr	1.3	1.4	0.5	2.0	1.0	2.4	1.1	1.6	1.0	2.0
Cu	1.9	1.4	1.2	1.3	1.9	3.3	1.9	2.0	0.9	10.9
Bi	1.0	1.1	0.9	1.1	0.7	1.3	1.0	1.0	1.0	0.8

TABLE 23. LAS VEGAS PARTICULATE EMISSION INVENTORY SUMMARY, TONS/YEAR (AFTER PEDCo[5])

Source category	1975
Fuel Combustion:	
Residential	37.2
Commercial/Institutional	134.4
Industrial	55.8
Industrial processes	2986.0
Burning	51.9
Mobile Sources:	
Aircraft	71.8
Railroad	13.5
Auto exhaust	795.7
Off-highway	206.8
Fugitive Dust Sources:	
Construction	620.0
Normal paved streets	2122.7
Dirty paved streets	43.7
Unpaved roads	5818.0
Sand and gravel pits	711.0
Agriculture	180.0
Cleared areas	2309.9
Heavy equipment storage	27.6
Playgrounds	5.0
Unpaved parking lots	38.5
Road shoulders[a]	
Railroad right-of-ways	202.9
Horse corrals	51.0
Natural surfaces	5591.7
Total	22074.3

[a] Road shoulder emissions included with unpaved parking lot emissions.

TABLE 24. RENO PARTICULATE EMISSION INVENTORY SUMMARY, TONS/YEAR (AFTER PEDCo[5])

Source category	1975
Fuel combustion	388.2
Industrial processes	23.0
Burning	1099.5
Mobile Sources:	
Aircraft	10.7
Railroad	24.7
Auto exhaust	437.3
Off-highway	85.5
Fugitive Dust Sources:	
Construction	814.0
Normal paved streets	1034.1
Dirty paved streets	20.6
Unpaved roads	3969.0
Sand and gravel pits	460.0
Agriculture	121.0
Street sanding	140.0
Cleared areas	40.1
Heavy equipment storage	3.4
Playgrounds	50.9
Unpaved parking lots	38.8
Road shoulders	2.8
Railroad right-of-ways	35.6
Horse corrals	9.0
Natural surfaces	2323.2
Total	11131.2

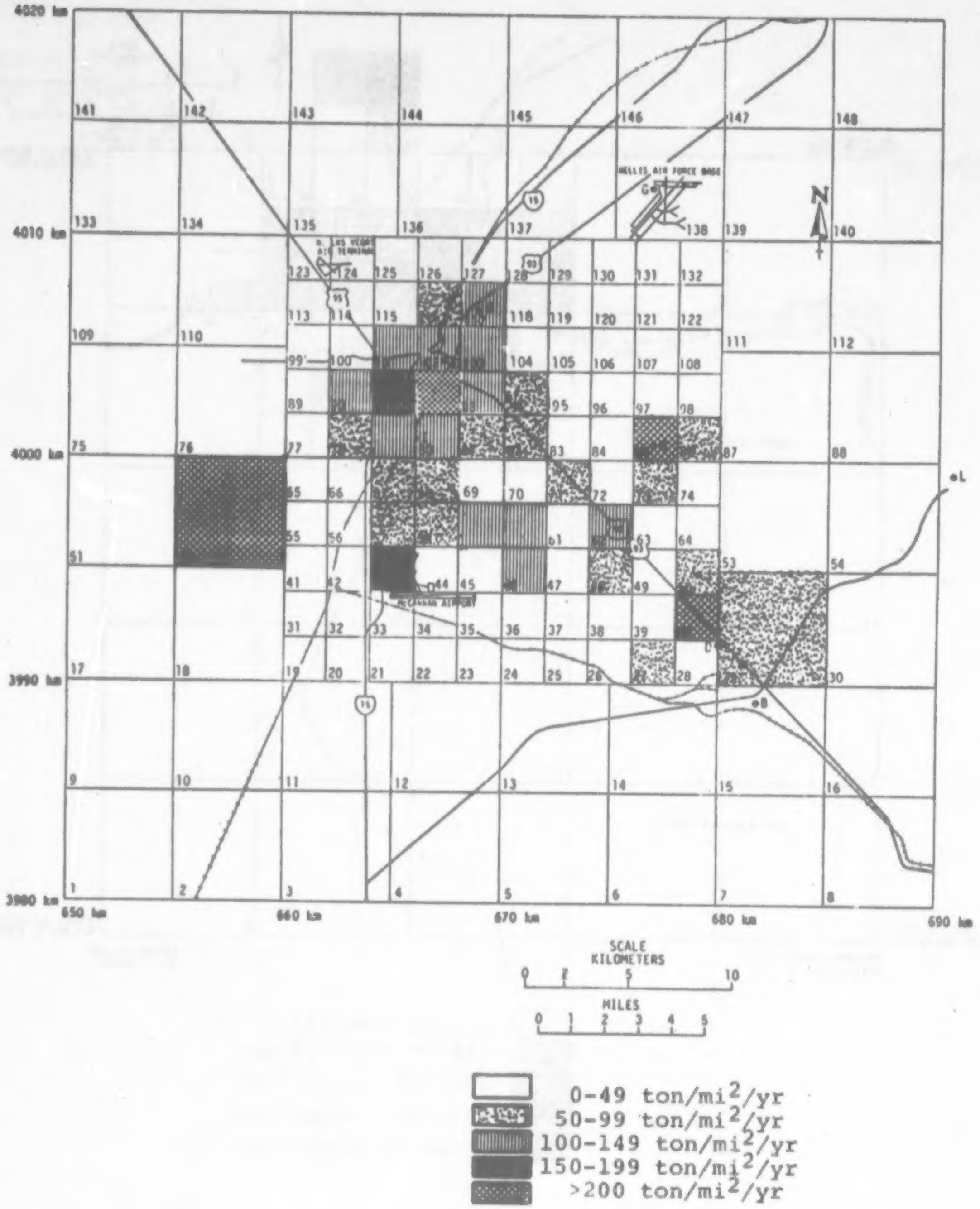

4020 km
4010 km
4000 km
3990 km
3980 km
650 km
660 km
670 km
680 km
690 km
NELLIS AIR FORCE BASE
N. LAS VEGAS AIR TERMINAL
McCARRAN AIRPORT
N
95
93
15
SCALE
KILOMETERS
0 2 5 10
MILES
0 1 2 3 4 5
0-49 ton/mi²/yr
50-99 ton/mi²/yr
100-149 ton/mi²/yr
150-199 ton/mi²/yr
>200 ton/mi²/yr

Figure 34. 1975 Las Vegas particulate emission density, ton/mi^2/yr. (After PEDCo[5]). Excludes emissions from natural surfaces.

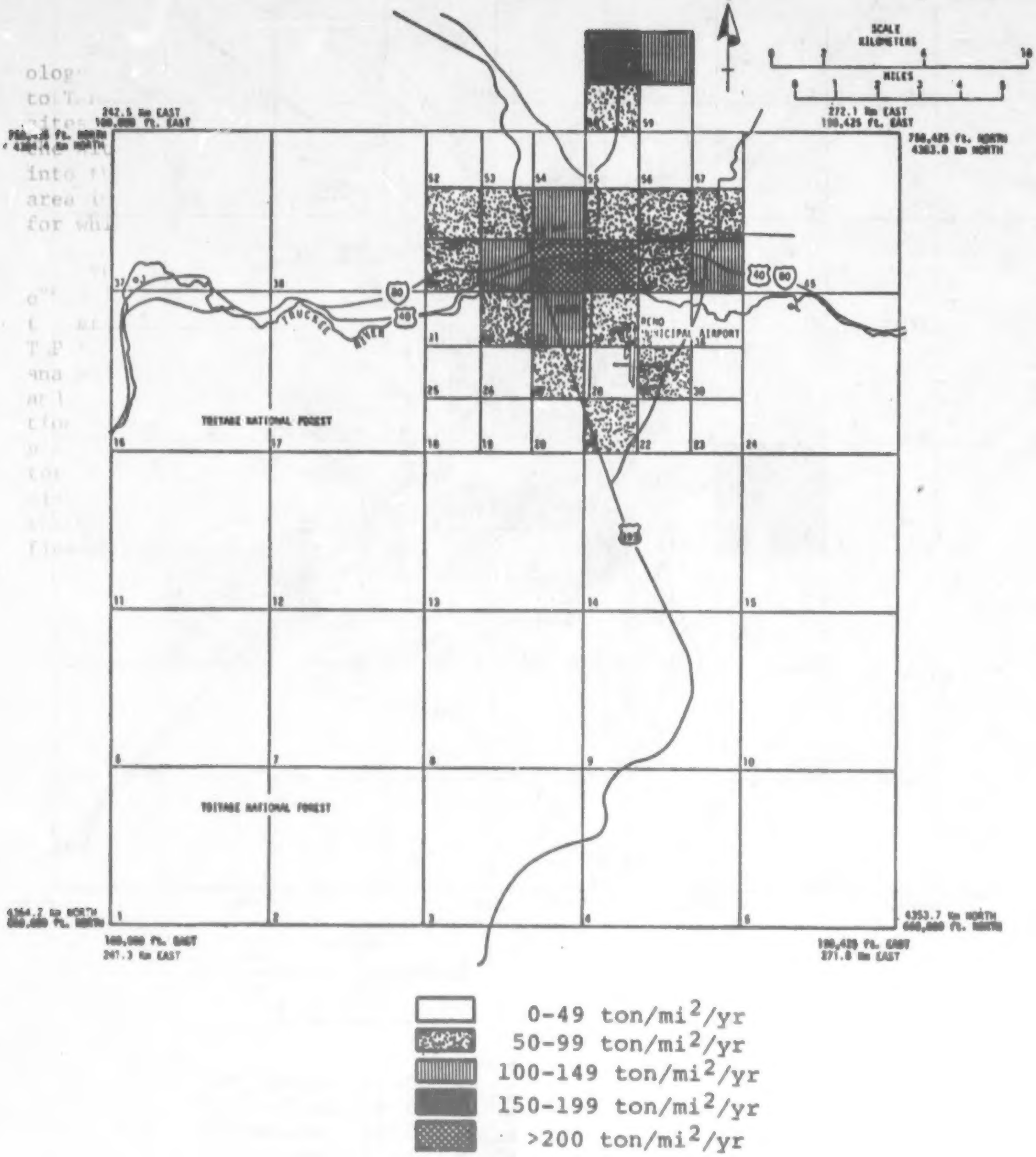

SCALE
KILOMETERS
0
2
6
10
MILES
0
1
2
3
4
5
242.5 Km EAST
100,000 Ft. EAST
272.1 Km EAST
190,425 Ft. EAST
750,425 Ft. NORTH
4363.0 Km NORTH
TRUCKEE RIVER
RENO MUNICIPAL AIRPORT
TOIYABE NATIONAL FOREST
80
40
395
4364.2 Km NORTH
660,000 Ft. NORTH
4353.7 Km NORTH
660,000 Ft. NORTH
100,000 Ft. EAST
247.3 Km EAST
190,425 Ft. EAST
271.8 Km EAST
0-49 ton/mi²/yr
50-99 ton/mi²/yr
100-149 ton/mi²/yr
150-199 ton/mi²/yr
>200 ton/mi²/yr

Figure 35. 1975 Reno particulate emission density, ton/mi^2/yr. (After PEDCo[5]). Excludes emissions from natural surfaces.

off-road surfaces. In Yuma County, travel on off-road surfaces is the primary source of emissions, followed by unpaved roads and exposed surfaces. The latter category consists of agricultural land and land cleared for development.

TABLE 25. 1976 TOTAL EMISSIONS BY SOURCE CATEGORY, (TONS/YR) (AFTER PEDCo[38])

Source category	Mohave county	Yuma county
Point Sources	631	924
Traditional Area Sources	736	3,968
Fugitive Dust Sources:		
Paved Roads	2,134	4,374
Unpaved Roads	105,830	66,045
Off-road Vehicles	99,375	183,425
Construction Activity	986	1,422
Agricultural Activity	26	8,172
Exposed Surfaces[a]	360	14,414
Total	210,078	282,744

[a] Includes emissions from agricultural surfaces and land cleared for development. Does not include emissions from undistrubed desert.

Other studies relied on the microinventory technique to analyze particulate problems. One such study prepared by Engineering Science for the U.S. Environmental Protection Agency,[6] analyzed particulate problems at five nonattainment sites in the Albuquerque, New Mexico area. The study inventoried all sources within a one-mile radius of the nonattainment monitors including fugitive dust sources such as paved and unpaved roads, areas subject to wind-erosion, and aggregate storage piles. The study utilized the Air Quality Display Model (AQDM) to relate emissions to ambient air quality. The report concluded that four anthropogenic fugitive dust sources — unpaved roads or driveways, paved roads, tire and exhaust emissions, and unpaved parking lots--contributed 42 to 61 percent of the TSP concentration at these five sites.

Another study[12] compiled microinventories for 35 nonattainment sites in Colorado and Utah as well as 8 nonattainment sites in Montana, Wyoming, and North Dakota. The authors concluded that "in general, the sources associated with nonattainment areas in the large urban centers of Region VIII such as Denver, Salt Lake City, Colorado Springs, and Pueblo were traffic-related reentrained dust from streets, winter road sanding, and motor-vehicle exhaust). In some moderate sized cities such as Grand Junction and Rapid City, traffic related emissions also appeared to be a major cause of high concentrations. However, in most of the medium and small cities, the major sources were point sources, unpaved roads, construction, and/or wind-blown dust from agricultural and open areas. None of the nonattainment sites were in rural locations."

Finally, a study by Technology Service Corporation[9] analyzed TSP/meteorology relationships in order to examine the contribution of wind-blown dust to TSP nonattainment in EPA Region VI. The study covered 25 nonattainment sites in four states: Arkansas, Oklahoma, Texas, and New Mexico. Seven of the sites, located in New Mexico as well as Western Texas and Oklahoma, fall into the study area for this report which is designated by the cross-hatched area in Figure 36. The discussion which follows focuses on these seven sites for which site descriptions are provided in Table 26.

The authors of the study used a variety of techniques to relate meteorological variables and TSP concentrations. One of the simpler analyses in the study assesses the contribution of wind-blown dust on days when measured TSP concentrations exceed the 24-hour primary or secondary NAAQS. In this analysis, the authors classify TSP concentrations according to the wind speed and precipitation observed on or before the day of the measurement. If violations of the 24-hour NAAQS at a site are associated with high winds and low precipitation, the authors conclude that wind-blown dust is a major contributor to high TSP concentrations at that site; if violations are usually associated with low winds and moderate to high precipitation, the authors conclude that wind-blown dust is only a minor contributor. Table 27 lists the classification of each of the seven sites in the study area.

TABLE 26. CLASSIFICATION OF SITES ACCORDING TO IMPORTANCE OF WIND-BLOWN DUST

Location	Class
Albuquerque (No. 1), NM	III
Albuquerque (No. 2), NM	III
Dona Ana, NM	II
Las Cruces, NM	II
Raton, NM	II
Roger Mills Co., OK	II
Lubbock, TX	III

Class II - wind-blown dust is a significant but not the major contributor, or there is uncertainty as to wind-blown dust contributions

Class III - wind-blown dust is the major contributor.

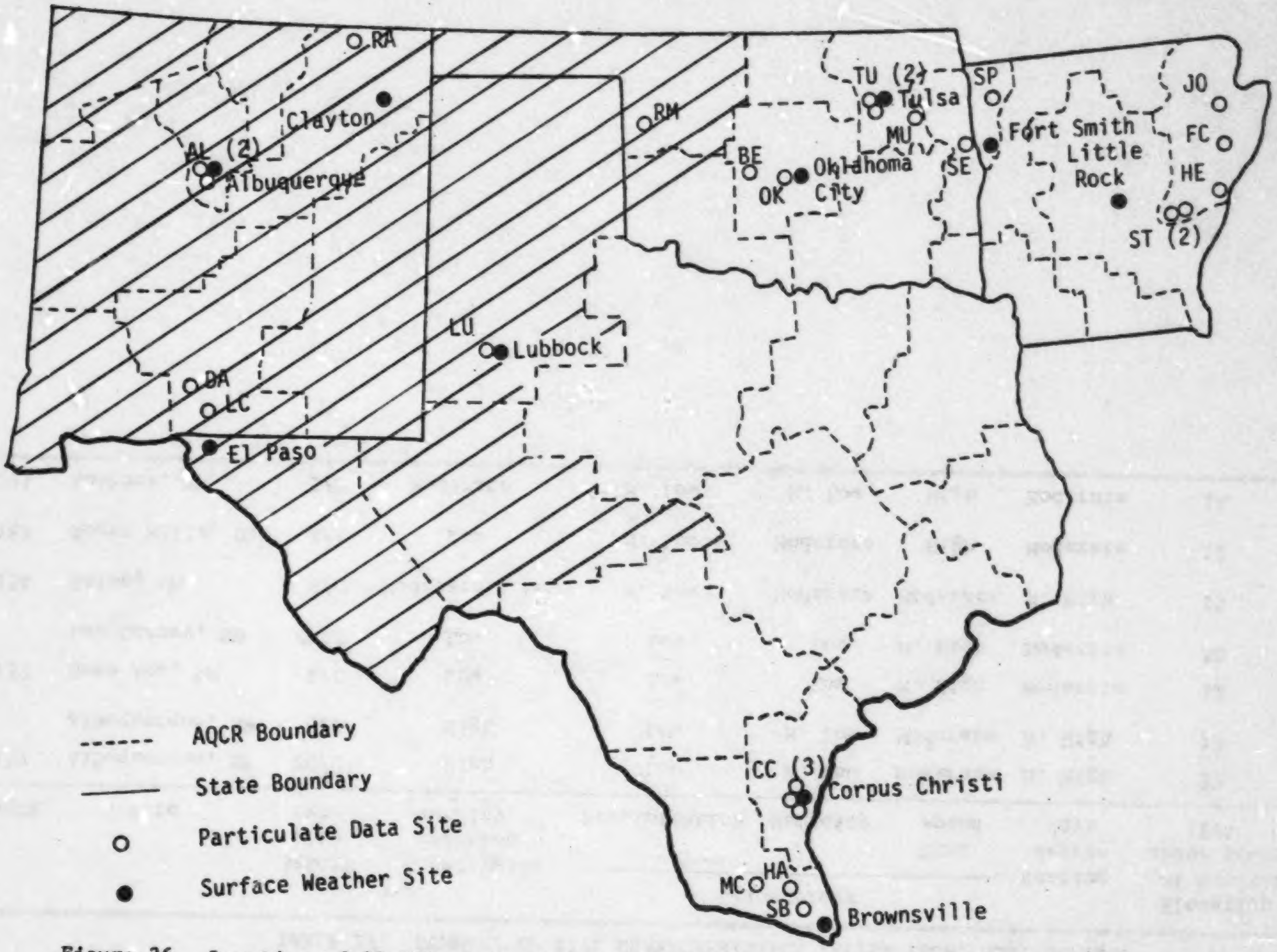

RA
Clayton
AL (2)
Albuquerque
DA
LC
El Paso
LU
Lubbock
RM
BE
OK
Oklahoma City
TU (2)
Tulsa
MU
SE
SP
Fort Smith
Little Rock
JO
FC
HE
ST (2)
CC (3)
Corpus Christi
MC
HA
SB
Brownsville
AQCR Boundary
State Boundary
Particulate Data Site
Surface Weather Site

Figure 36. Location of 25 TSP monitoring stations shown in the regional map of AQCRs. (Numerals in parentheses indicate the number of stations in a same city. After Tech. Ser. Corp[9]).

TABLE 27. SUMMARY OF SITE CHARACTERISTICS (AFTER TECH. SER. CORP.[9])

AQCR	Site	SAROAD site type	Countrywide emission density	Climatology				Heating degree days	Elevation of monitor above ground (ft)
				Precipitation	Humidity	Wind speed			
152	Albuquerque, NM	CC/C	High	Low	M. Low	Moderate		M. High	29
	Albuquerque, NM	S/C	High	Low	M. Low	Moderate		M. High	13
153	Dona Ana, NM	R/C	Low	Low	Low	M. High		Moderate	12
	Las Curces, NM	CC/C	Low	Low	Low	M. High		Moderate	50
154	Raton, NM	S/C	Moderately Low	M. Low	Moderate	Moderate		M. High	15
187	Roger Mills, OK	R/A	Low	M. Low	Moderate	High		Moderate	12
211	Lubbock, TX	S/C	Moderate	M. Low	M. Low	High		Moderate	14

Although this analysis implicates wind-blown dust as a significant contributor at all seven sites in the study area, the authors of the report had some reservations about this conclusion. Results of a more detailed analysis, described below, indicated that man-made sources played a greater role in high TSP concentrations than wind-blown dust at most of the sites listed in Table 27. The authors suggested two possible explanations for this discrepancy. (1) Both conclusions may be correct. The simpler analysis deals only with days when TSP concentrations exceed primary or secondary standards. The authors speculated that wind-blown dust from desert pavement, agricultural lands, construction sites, etc., may play a greater role on such days than on more typical days. (2) The results of one of the analyses may be incorrect. The authors expressed greater confidence in the more detailed analysis described below, noting that it relied on all the sampling days rather than just a few and used many more variables to explain variations in TSP concentrations. The detailed analysis used the AID (Automated Interactive Decision) decision-tree program developed at the University of Michigan Institute for Social Research. This program accounts for the variance in the dependent variable (TSP) by splitting the data according to ranges in the independent (meteorological) variables, each time choosing the split that maximizes the variance explained in the dependent variable. The study examined the 18 meteorological variables listed in Table 28 to explain the variance in 24-hour TSP concentrations at the 25 study sites.

Figure 37 illustrates the output from the AID decision-tree program for a site in Raton, New Mexico. The output indicates that seasonal fluctuations account for most of the variance in TSP concentrations at this site; TSP concentrations average 27.9 $\mu g/m^3$ during January and February compared with 52.5 $\mu g/m^3$ during the rest of the year. Other important explanatory variables at this site include temperature, wind direction, and wind speed. Higher TSP concentrations are associated with high temperatures (greater than 40^oF), winds from the east, and low average wind speed (less than 7 knots).

To assess the contribution of wind-blown dust, the analysts drew conclusions based on their interpretation of the meteorological variables that are important at each site. At the Raton, New Mexico, site, for example, they concluded that man-made sources, mostly to the east, were the primary contributors to high TSP concentrations. As Table 29 indicates, the authors of the study concluded that man-made sources - including some fugitive dust sources - were the principal contributors to high TSP concentrations at all five of the sites in New Mexico and at the Roger Mills site in Oklahoma. Wind-blown dust, which includes dust from construction activities and agricultural lands as well as dust from undisturbed desert areas, was the primary contributor at Lubbock, Texas, and was listed as a potential contributor at the other six sites as well.

TABLE 28. SUMMARY OF METEOROLOGICAL VALUES

Variable
Month of the Year
Daytime Average Visibility
Number Observations Blowing Dust
Arithmetic Average Wind Speed
Vector Average Wind Direction
Average Relative Humidity
Wind Variability
A.M. Mixing Height
A.M. Average Wind Speed Through Mixing Layer
P.M. Mixing Height
P.M. Average Wind Speed Through Mixing Layer
Maximum Temperature
Minimum Temperature
Amount of 1-Day Precipitation
Maximum Wind Speed
3-Day Accumulated Precipitation
Number of Days Since Last Precipitation or Snow Cover
Number of 1-Day Precipitation Observations

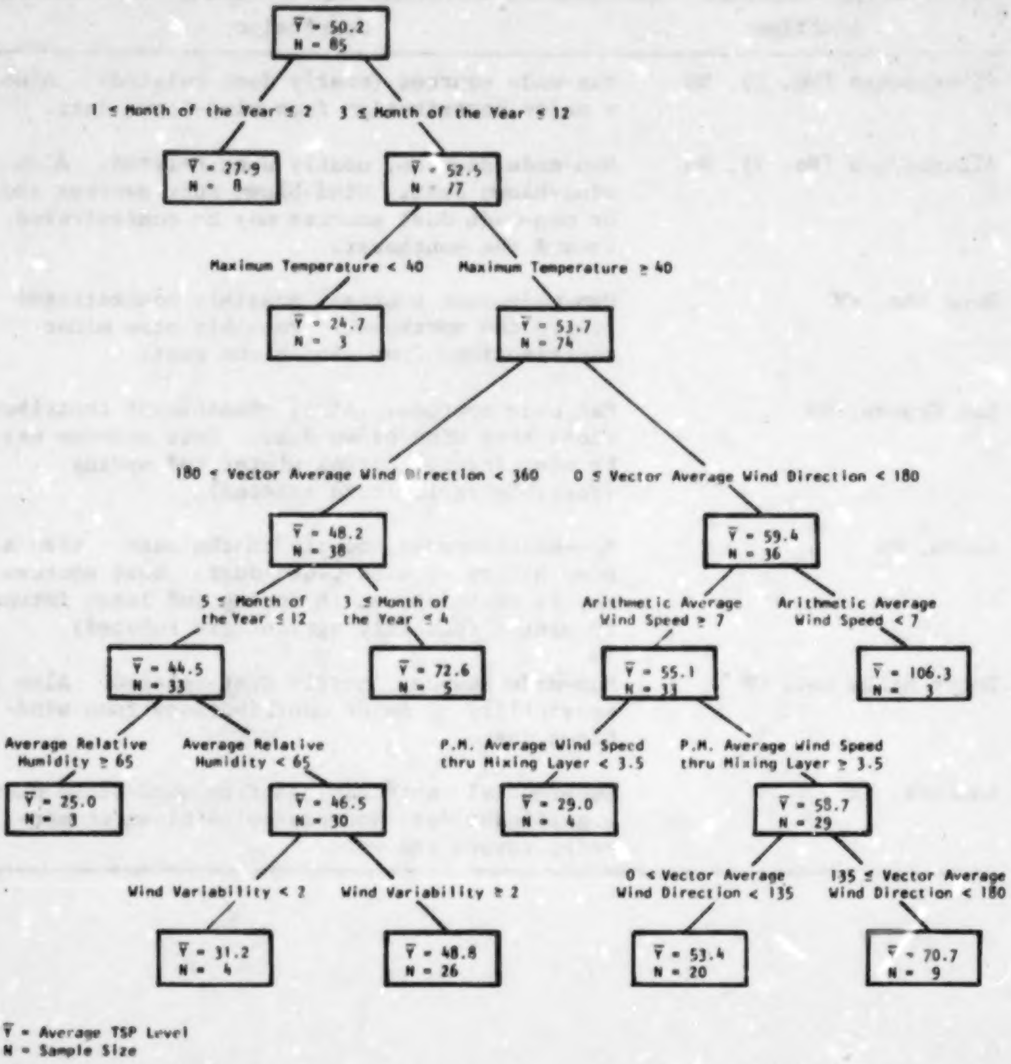

Ȳ = 50.2
N = 85
1 ≤ Month of the Year ≤ 2
3 ≤ Month of the Year ≤ 12
Ȳ = 27.9
N = 8
Ȳ = 52.5
N = 77
Maximum Temperature < 40
Maximum Temperature ≥ 40
Ȳ = 24.7
N = 3
Ȳ = 53.7
N = 74
180 ≤ Vector Average Wind Direction < 360
0 ≤ Vector Average Wind Direction < 180
Ȳ = 48.2
N = 38
Ȳ = 59.4
N = 36
5 ≤ Month of the Year ≤ 12
3 ≤ Month of the Year ≤ 4
Arithmetic Average Wind Speed ≥ 7
Arithmetic Average Wind Speed < 7
Ȳ = 44.5
N = 33
Ȳ = 72.6
N = 5
Ȳ = 55.1
N = 33
Ȳ = 106.3
N = 3
Average Relative Humidity ≥ 65
Average Relative Humidity < 65
P.M. Average Wind Speed thru Mixing Layer < 3.5
P.M. Average Wind Speed thru Mixing Layer ≥ 3.5
Ȳ = 25.0
N = 3
Ȳ = 46.5
N = 30
Ȳ = 29.0
N = 4
Ȳ = 58.7
N = 29
Wind Variability < 2
Wind Variability ≥ 2
0 ≤ Vector Average Wind Direction < 135
135 ≤ Vector Average Wind Direction < 180
Ȳ = 31.2
N = 4
Ȳ = 48.8
N = 26
Ȳ = 53.4
N = 20
Ȳ = 70.7
N = 9
Ȳ = Average TSP Level
N = Sample Size

Figure 37. Example of AID output.

TABLE 29. SUMMARY OF CONCLUSIONS FROM THE INTERPRETATION OF THE AID DECISION TREES

Location	Conclusion
Albuquerque (No. 1), NM	Man-made sources (mostly dust related). Also, a major contribution from wind-blown dust.
Albuquerque (No. 2), NM	Man-made sources, mostly dust related. Also wind-blown dust. Wind-blown dust sources and/or man-made dust sources may be concentrated toward the southeast.
Dona Ana, NM	Man-made dust sources, possibly concentrated toward the northeast. Possibly some minor contributions from wind-blown dust.
Las Cruces, NM	Man made sources. Also, significant contributions from wind-blown dust. Dust sources may be most intense during winter and spring (possibly agriculture related).
Raton, NM	Man-made sources, mostly to the east. Also a possibility of wind-blown dust. Dust sources may be most intense in spring and least intense in winter (possibly agriculture related).
Roger Mills Co., OK	Man-made sources, mostly dust related. Also a possibility of major contributions from wind-blown dust.
Lubbock, TX	Substantial contributions from wind-blown dust. Significant dust sources (wind-blown or man-made) toward the west.

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APPENDIX A

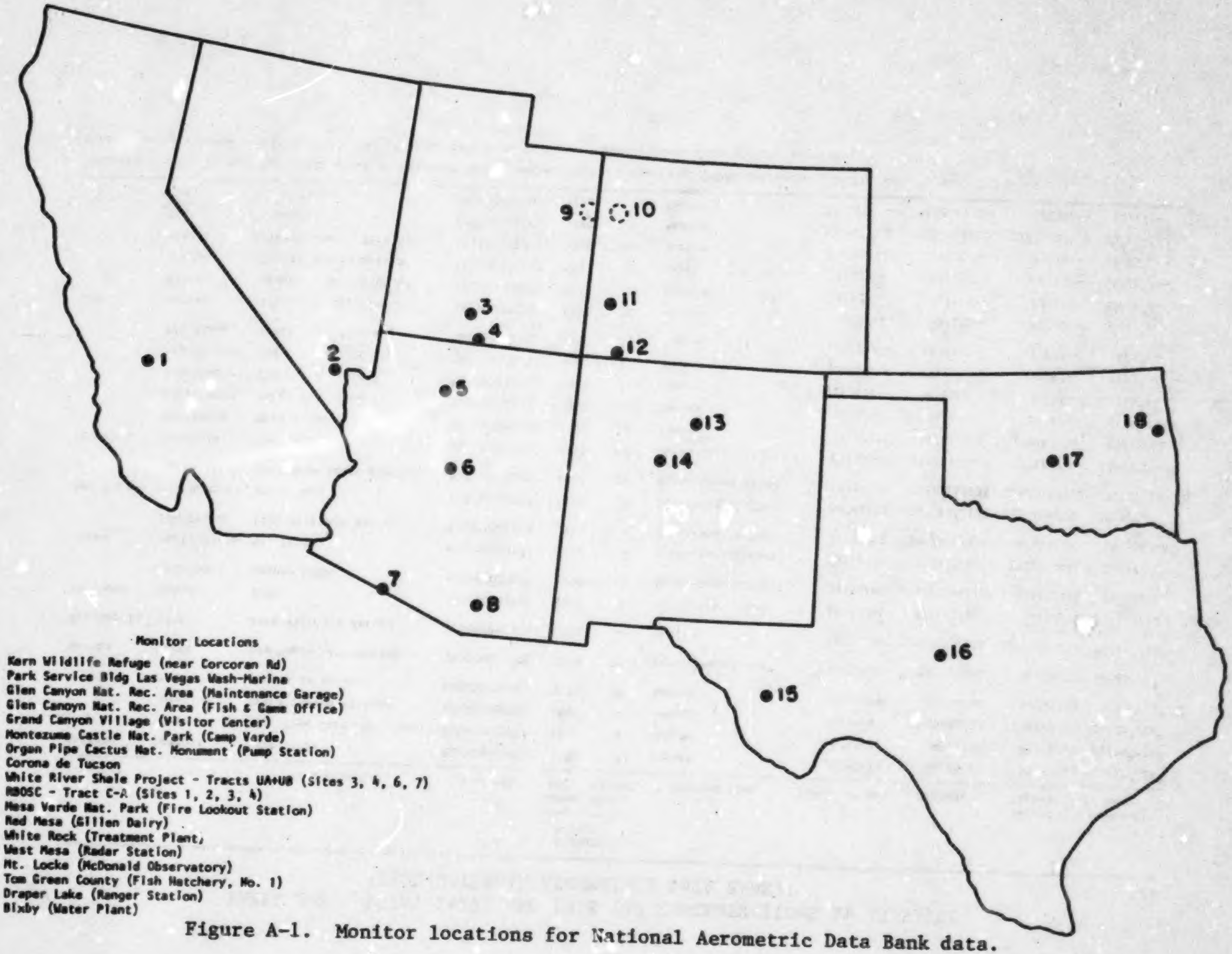
BACKGROUND STATION INFORMATION

TABLE A-1. 1976, 1977, AND 1978 TSP CONCENTRATIONS AT 33 SITES (FROM NATIONAL AEROMETRIC DATA BANK)

State	County	Site location	Site code	Elevation (ft)		Station type	Number of OBS	Highest	Second highest	Geometric mean
				Above MSL	Above ground					
Arizona	Yavapai	Camp Verde	030940002F03	3381	4	Remote	52/30/33	64/68/49	59/65/49	30/29[a]/24[a]
	Pima	Org. Pipe Cact. Nat. Mon.	030620005F03	1661	4	Remote	48/42/31	139/83/98	83/78/49	33/34[a]/31[a]
	Coconino	Grand Canyon Village	030370001F03	6955	4	Remote	36/37/9	69/82/27	58/42/27	14/20[a]/14[a]
	Pima	Corona de Tucson	030620008G03	3225	13	Remote	52/45/29	51/84/40	42/45/33	5/25[a]/17[a]
Nevada	Clark	Las Vegas Wash-Marina	290080011G03	1300	25	Rural-Unqualified	52/52/20	115/79/92	91/78/71	37/38/24[a]
California	Kern	Kern Wildlife Refuge	053480001I03	0215	4	Remote	48/36/34	390/196/450	222/157/203	84/76[a]/62
Oklahoma	Tulsa	Bixby	373020133F03	0918	18	Rural-Near Urban	19/62/61	87/110/98	76/95/91	33[a]/38/40
	Oklahoma	Draper Lake	372200020F03	1290	15	Rural-Agricultural	59/56/61	147/3094/116	138/162/105	50/51/47
Texas	Jeff. Davis	Mt. Locke	452740003F03	6791	4	Rural-Agricultural	42/51/40	221/99/66	131/71/44	20/18/18
	Tom Green	Fish Hatchery No. 1	455200001F03	1864	15	Rural-Near Urban	21/53/32	391/191/154	94/127/98	56[a]/50/48[a]
New Mexico	Los Alamos	White Rock	320720001F03	6265	15	Rural-Unqualified	59/61/25	147/134/172	123/104/38	30/32/22[a]
	Bernalillo	West Mesa Radar Station	320140031H03	6003	29	Rural-Unqualified	60/57/58	238/314/235	236/116/132	37/27/19
Colorado	La Plata	Red Mesa	061300001F03	6520	10	Rural-Agricultural	61/53/--	189/280/---	172/188/---	43/34[a]/--
	Montezuma	Mesa Verde	061530003F03	7060	15	Remote	77/57/77	132/125/38	102/92/38	13/15/12
	Rio Blanco	Tract C-A, Site 1	061860001J03	7360	197	Remote	103/6/--	81/6/--	80/5/--	11/4[a]/--
	Rio Blanco	Tract C-A, Site 2	061860002J03	7360	33	Remote	121/10/--	57/10/--	57/6/--	11/4[a]/--
	Rio Blanco	Tract C-A, Site 3	061860003J03	6600	33	Remote	124/10/--	281/14/--	210/8/--	17/3[a]/--
	Rio Blanco	Tract C-A, Site 4	061860004J03	6300	33	Remote	121/10/--	182/39/--	173/9/--	14/5[a]/--
Utah	Uintah	Tracts UA+UB, Site A7	461200007J03	5360	20	Remote	60/3/--	78/22/--	42/20/--	14/17[a]/--
	Uintah	Tracts UA+UB, Site A6	461200006J03	5250	20	Remote	61/2/--	101/31/--	72/23/-	20/27[a]/--
	Uintah	Tracts UA+UB, Site A4	461200004J03	5717	20	Remote	61/3/--	64/15/--	60/12/--	15/31[a]/--
	Uintah	Tracts UA+UB, Site A3	461200003J03	5320	20	Remote	61/3/--	39/20/--	36/16/--	12/15[a]/--
	Kane	Glen Canyon	460400002F03	3890	5	Remote	202/340/156	118/661/156	114/322/143	23[a]/24/11
	Kane	Glen Canyon	460400001F03	3750	5	Remote	272/326/--	120/423/--	115/258/--	15/17/--

[a] Denotes a value derived from data which do not meet SAROAD summarization criteria of OAQPS Guideline 1.2-040, Vol. 3, Sec. 2.3.0.

Note: Concentrations for 1976, 1977, and 1978 are tabulated in chronological order, separated by slashes.



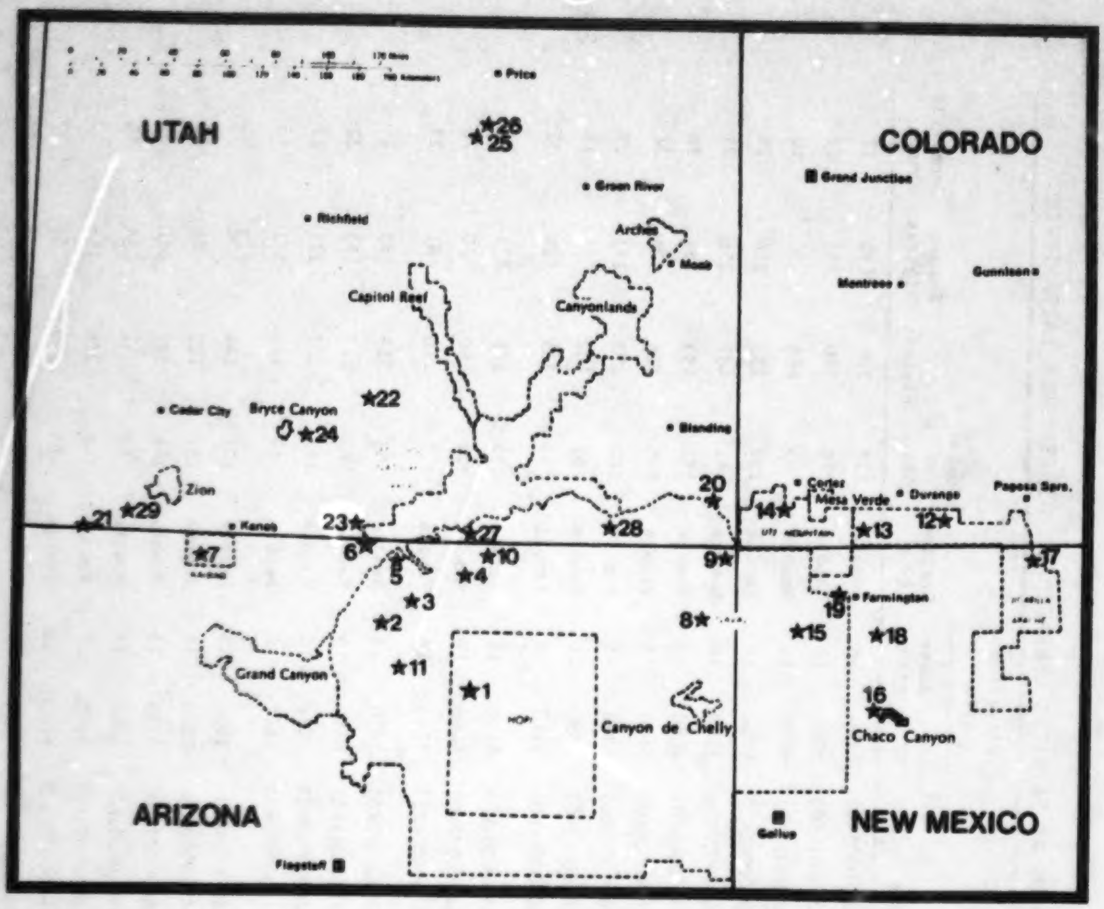
Monitor Locations

1. Kern Wildlife Refuge (near Corcoran Rd)
2. Park Service Bldg Las Vegas Wash-Marina
3. Glen Canyon Nat. Rec. Area (Maintenance Garage)
4. Glen Canoyn Nat. Rec. Area (Fish & Game Office)
5. Grand Canyon Village (Visitor Center)
6. Montezuma Castle Nat. Park (Camp Verde)
7. Organ Pipe Cactus Nat. Monument (Pump Station)
8. Corona de Tucson
9. White River Shale Project - Tracts UA+UB (Sites 3, 4, 6, 7)
10. RBOSC - Tract C-A (Sites 1, 2, 3, 4)
11. Mesa Verde Nat. Park (Fire Lookout Station)
12. Red Mesa (Gillen Dairy)
13. White Rock (Treatment Plant,
14. West Mesa (Radar Station)
15. Mt. Locke (McDonald Observatory)
16. Tom Green County (Fish Hatchery, No. 1)
17. Draper Lake (Ranger Station)
18. Bixby (Water Plant)

Figure A-1. Monitor locations for National Aerometric Data Bank data.

TABLE A-2. 1976 TSP CONCENTRATIONS AT 26 SITES OPERATED BY UTE RESEARCH LABORATORIES

State	County	Site Location	Site code	Elevation (ft) Above MSL	Elevation (ft) Above ground	Station type	Number of OBS	Highest	Second highest	Geometric mean
Arizona	Navajo	Bacobi	030520003K03	6300	16	Remote	137	208	155	17
	Conconino	Bodaway	030200012K03	5960	16	Remote	76	370	353	22
	Coconino	Coppermine	030200011K03	6050	16	Remote	93	663	90	18
	Coconino	Kaibito	030200010K03	6000	16	Remote	152	253	216	29
	Coconino	Lee's Ferry	030200007K03	3190	16	Remote	61	481	256	21
	Mohave	Piute	030500009K03	4880	16	Remote	151	193	134	18
	Apache	Redrock	030040000K03	6110	16	Remote	155	128	125	24
	Apache	Teec Nos Pos	030040001K03	4990	16	Remote	141	473	171	29
	Coconino	Tsa Schizzi	630200013K03	5550	16	Remote	67	102	57	16
	Coconino	Tuba City	030200014K03	5170	16	Remote	99	305	124	32
Colorado	La Plata	Ignacio	061300003K03	6550	16	Remote	131	188	171	23
	La Plata	Redmesa	061300002K03	6460	16	Remote	121	80	70	24
	Montezuma	Towaoc	061600004K03	5740	16	Remote	113	110	81	23
New Mexico	San Juan	Burnham	321000012K03	5610	16	Remote	83	569	185	24
	San Juan	Chaco Canyon	321000011K03	6190	16	Remote	75	113	111	31
	Rio Arriba	Dulce	320920003K03	7220	16	Remote	153	207	171	12
	San Juan	Huerfano	321000007K03	6140	16	Remote	118	174	171	45
Utah	San Juan	Aneth	46096003K03	4590	16	Remote	157	144	138	30
	Washington	Boomington	46128001K03	2520	16	Remote	152	123	86	26
	Garfield	Escalante	460300002K03	5755	16	Remote	141	592	360	56
	Kane	Glen Canyon	460400003K03	4040	16	Remote	59	36	34	15
	Garfield	Henrieville	460300003K03	5905	16	Remote	143	308	196	42
	San Juan	Navajo Mtn.	460960001K03	6050	16	Remote	13	99	56	22
	San Juan	Oljato	460960002K03	4810	16	Remote	150	207	193	26
	Washington	St. George	461280002K03	2880	16	Remote	62	57	46	16


UTAH
COLORADO
ARIZONA
NEW MEXICO
Price
Green River
Richfield
Arches
Moab
Grand Junction
Montrose
Gunnison
Capitol Reef
Canyonlands
Cedar City
Bryce Canyon
Blanding
Zion
Kanab
Cortez
Mesa Verde
Durango
Pagosa Spgs.
Farmington
Grand Canyon
HOPI
Canyon de Chelly
Chaco Canyon
Gallup
Flagstaff
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★ indicates Ute Research Laboratories' monitoring stations:

1 Babcobi, AZ
2 Bodaway, AZ
3 Coppermine, AZ
4 Kaibito, AZ
5 Lechee, AZ
6 Lee's Ferry, AZ
7 Piute, AZ
8 Redrock, AZ
9 Teec Nos Pos, AZ
10 Tsa Schizzi,
11 Tuba City, AZ
12 Ignacio, CO
13 Redmesa, CO
14 Towaoc, CO
15 Burnham, NM
16 Chaco Canyon, NM
17 Dulce, NM
18 Huerfano, NM
19 Navajo Farm Proj., NM
20 Aneth, UT
12 Bloomington, UT
22 Escalante, UT
23 Glen Canyon, UT
24 Henrieville, UT
25 Huntington Canyon, No. 1, UT
26 Huntington Canyon, NO. 2, UT
27 Navajo Mountain, UT
28 Oljato, UT
29 St. George, UT

Figure A-2. Monitoring site locations (from EPA-600/7-79-135, p. 5, Reference 10).

TABLE A-3. ACTIVATION DATES FOR SITES OPERATED BY UTE RESEARCH LABORATORIES

Monitoring site	Activation date	Monitoring site	Activation date
Bacobi, AZ	02/27/76	Chaco Canyon, NM	06/30/76
Bodaway, AZ	06/21/76	Dulce, NM	05/17/76
Coppermine, AZ	02/02/76	Huerfano, NM	04/13/76
Kaibito, AZ	01/22/76	Navajo Farm Project, NM	02/06/77
Lechee, AZ	05/22/77	Aneth, UT	02/11/76
Lee's Ferry, AZ	10/05/76	Bloomington, UT	02/02/77
Piute, AZ	01/27/76	Escalante, UT	01/24/76
Redrock, AZ	01/12/76	GLen Canyon, UT	10/13/76
Teec Nos Pos, AZ	01/20/76	Henrieville, UT	01/24/76
Tsa Schizzi, AZ	04/02/76	Huntington Canyon, No. 1, UT	01/18/77
Tuba City, AZ	01/16/76	Huntington Canyon, NO. 2, UT	05/06/77
Ignacio, CO	01/19/76	Navajo Mountain, UT	01/30/77
Redmesa, CO	04/19/76	Oljato, UT	01/23/76
Towaoc, CO	04/29/76	St. George, UT	07/14/76
Burnham, NM	05/17/76		

Note: No uniform sampling schedule was in use in 1976, but sampling was required for three 24-hour periods each week.